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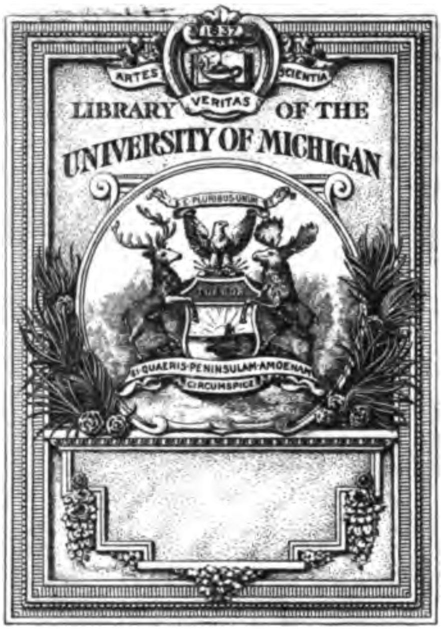

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U. S. DEPARTMENT OF AGRICULTURE.

U.S. WEATHER BUREAU.

BULLETIN I.

ECLIPSE METEOROLOGY AND ALLIED PROBLEMS.

PREPARED UNDER DIRECTION OF WILLIS L. MOORE, CHIEF OF WEATHER BUREAU,

BY

FRANK H. BIGELOW, M. A., L. H. D.,

PROFESSOR OF METEOROLOGY.

WASHINGTON:
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture, Weather Bureau,
Washington, D. C., March 10, 1902.

Sir: I have the honor to transmit herewith a Report on Eclipse Meteorology and Allied Problems, by Prof. Frank H. Bigelow, of the Weather Bureau, and recommend that it be published as a bulletin of the Weather Bureau.

At the time of the total solar eclipse of May 28, 1900, there was much interest among scientists in several questions growing out of the effect of the moon's shadow upon the earth's atmosphere, and under my direction the Weather Bureau made some contributions to the subject by conducting special meteorological observations throughout the Southern States, and by sending a small expedition to Newberry, S. C. The result of this work, together with a discussion of allied topics, is presented by Professor Bigelow in this report.

Very respectfully,

Willis L. Moore,
Chief United States Weather Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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PREFACE.

The following report on the operations of the United States Weather Bureau in connection with the observations of the total eclipse of the sun, May 28, 1900, is based upon the records of the expedition to Newberry, S. C.; upon the special meteorological observations at sixty-two Weather Bureau stations located within 500 miles of the center of the track of totality; upon a considerable number of voluntary special observations executed within the belt of the umbra, in accordance with the instructions of the Washington office; and upon a study of various problems in solar and terrestrial meteorology. As the outcome of this work there have been made special studies, (1) on the apparatus planned to obtain a large-image picture of the inner corona, while yet employing a telescope of comparatively short focus; (2) on the shadow band phenomena, which appear to be due to meteorological conditions exclusively, and are not to be associated with diffraction on the edge of the moon; and (3) on the variations of the pressure, temperature, vapor tension, and wind caused by the passage of the shadow cone, together with a computation on the number of calories of heat absorbed per kilogram of air.

Furthermore, it seemed proper to extend the scope of the discussion somewhat beyond these limits for the following reasons: The recent rapid and magnificent advances in physics, especially in connection with the subject of the ionization of gases and the attendant effects in electricity and magnetism, have drawn the attention of students with renewed vigor to several problems which have for many years baffled all efforts at their solution. Thus the relations of electricity and magnetism in the sun to the production of the solar corona, and their correlated influences in the earth's atmosphere, have certainly been of late so far elucidated as to open up new lines of research, even if we have not in reality entered already upon the correct path which leads to the true solution. The range of information is very wide, and the number of papers to be examined is so great that only specialists are likely to obtain a clear idea of the status of these questions. After diligent study the conviction is much strengthened in my mind that the meteorologist stands in the best position of all to correlate the allied topics of solar physics, atmospheric electricity and magnetism, and the dynamic actions within the gaseous envelopes of both the sun and the earth. In fact the principles of meteorology embrace properly these two fields, since they are connected together by the bonds of radiation and absorption, so that the formulæ of thermodynamics and hydrodynamics have similar applications in each of them. I have heretofore shown in my other papers that the polar regions of the sun are stripped of coronal rays, and that these first appear in a collar or ruffle at some distance from the poles. But this is the exact phenomenon that results from subjecting a conducting sphere emitting cathode discharges in low-pressure gases to the action of a magnetic field, from which it is inferred that the sun acts like a magnetic body, and that the photospheric envelope is the seat of powerful electrical oscillatory discharges. It has been also found that the earth is immersed in an external magnetic field, upon which is superposed a secondary field, probably due to the action of ionization in the air, and that a term in atmospheric electricity is simultaneously produced by this cause. The diurnal variations of the atmospheric magnetic and electric fields are thus only other manifestations of the forces which cause ionization. Therefore, the conclusion can not be avoided that large interests in the study of terrestrial magnetism, as well as of atmospheric electricity, belong to the meteorologist, because part of the magnetic force is apparently produced throughout the atmosphere by the effects of solar radiation acting on its atomic and molecular constituents.

These recent researches are of primary importance to our own observers if we intend to maintain our proper place in the advancement of science. There is great danger that they will not be properly instructed in such matters unless suitable explanations of these results are placed before them. It has seemed desirable, on this account, to devote some attention to the work of exposition and review, by which at least a fair impression may be gained of the direction in which meteorology is moving, and the progress that has been already made. The belief will doubtless be strengthened in many minds that these branches of science are closely interwoven with one another, and that we can not afford to let any of these important lines of research escape our attention. A few sections of a mathematical character are added for the use of those students who seek to refresh their memory by ready references to the formulæ, and to guide others in the right course of study when they seek to seriously enter upon these problems. An effort has been made to show the connection between the MAXWELL, the J. J. THOMSON, and the HEAVISIDE systems of electric and magnetic formulæ, on account of the growing importance of the fundamental investigations which have been executed by Mr. O. HEAVISIDE.

FRANK H. BIGELOW.

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CHAPTER 1.

THE WORK OF THE UNITED STATES WEATHER BUREAU IN CONNECTION WITH THE TOTAL ECLIPSE OF THE SUN MAY 28, 1900, AT NEWBERRY, S. C.

THE WEATHER CONDITIONS.

The track of the total eclipse of the sun which occurred on May 28, 1900, passed over the Southeastern States, from New Orleans to Norfolk, as shown on Chart 1. This location of the track was very convenient for the installation of astronomical apparatus, as compared with the cases where the track crosses the unsettled districts of the earth, and it was evident that many parties would undertake scientific observations along the path indicated. Since the weather conditions are necessarily a prime factor in the procurement of valuable results, it was proper that special efforts should be made by the Weather Bureau to secure, by a preliminary survey of the meteorological conditions of the region, an approximate idea of the probable state of the sky relative to the several portions of the track. Those places which showed a special liability to cloudiness at the time of the eclipse ought to be avoided, and preference given to those which promised a clearer, purer atmosphere. In consequence of this obligation, such preparatory information was obtained by a survey of the sky during the three preceding years, and special reports on the subject were issued for the information of astronomers. It may be stated that the forecast work of the Weather Bureau was recognized in two ways: (1) The astronomical parties all selected sites within the region which was indicated by the result of the survey as likely to be the more promising; (2) the council of the Astronomical and Astrophysical Society of America passed a special resolution, which was forwarded to the Chief of the Weather Bureau, in the following terms:

> *Resolved*, That the Astronomical and Astrophysical Society of America extends to the Chief of the United States Weather Bureau its hearty thanks for his courtesy in transmitting daily weather bulletins to those astronomers who observed within the United States the total solar eclipse of May 28, 1900.

Fortunately, the weather conditions on the morning of May 28 proved to be exceptionally satisfactory throughout the track, so that very few observations which had been planned failed on account of clouds or rain. Indeed, it is very rare that such good fortune as regards weather attends so many eclipse expeditions as were located in the United States on that occasion. There was a little cloudiness and a showery condition in Georgia, but in all other places the air was clear and very quiet, the temperatures were moderate, and the pressure relatively high. To the north of the Ohio Valley and Pennsylvania there was more or less rain, and in that district the weather would have been unfavorable for observing the eclipse. The weather conditions on the morning of the eclipse—8 a. m., May 28, 1900—are shown on Chart 2. The shaded areas indicate precipitation during the preceding twelve hours.

TABLE 1.—*Path of the shadow over the United States from New Orleans, La., to Norfolk, Va.*

Number	Time		Northern limit of shadow path		Central line		Southern limit of shadow path		Duration of totality on the central line
	Greenwich mean time	Local mean time (a. m.)	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude	
	d h m	*h m*	° ′	° ′	° ′	° ′	° ′	° ′	*m s*
1	May 28 1 30	7 27.4	+29 56.3	91 5.1	+20 46.5	90 39.7	+29 36.7	90 14.3	1 12.6
2	1 35	7 47.1	31 47.7	87 22.8	31 36.0	86 58.2	31 24.3	86 33.6	1 19.6
3	1 40	8 5.2	33 25.0	84 5.2	33 11.8	83 41.4	32 58.6	83 17.6	1 26.0
4	1 45	8 22.2	34 51.9	81 4.1	34 37.3	80 41.1	34 22.7	80 18.1	1 31.7
5	1 50	8 39.5	36 10.3	78 14.6	35 54.4	77 52.4	35 38.5	77 30.2	1 37.0
6	1 55	8 54.2	37 21.7	75 33.5	37 4.6	75 12.1	36 47.5	74 50.7	1 41.9

Table 1 gives the location of the path, the times of the occurrence, and the duration of the totality on the central line at the six places marked by lines crossing the track, as shown on Chart 1. It states that the duration of the totality increases from about 72 seconds near New Orleans to about 100 seconds near Norfolk, and this would suggest a choice of locality for the eclipse stations as far eastward as possible.

The results of the observations on cloudiness were published in three reports for 1897, 1898, and 1899, and the summary of them is contained in Table 2. This records the fact that each of the three years testifies that a minimum of cloudiness should be found in Georgia and South Carolina, and a maximum near the Atlantic and also near the Gulf coasts. Accordingly, one would prefer a site on the high land of the Appalachian range, and in consequence avoid the Norfolk district. This brought up a conflict of interests, since there was a gain of time by going eastward, but an increase of risk from cloudiness, and hence a compromise of some sort was necessary. The stations actually occupied by the large observing parties are shown on Chart 1, and it indicates that astronomers preferred to sacrifice a few seconds of time rather than take the chances of observing in the hazy conditions likely to prevail in the low country adjoining the ocean. Newberry, in South Carolina, just to the northwest of Columbia, was selected by the Weather Bureau party, whose work is described in this report.

TABLE 2.—*Summary of the meteorological results for three years, 1897, 1898, 1899.*

[The figures are percentages of cloudiness.]

State	1897		1898		1899		Means	
	General sky	Near sun	General sky	Near sun	General sky	Near sun	General sky	Near sun
Virginia	....	....	44.9	41.7	35.7	34.3	40.3	38.0
North Carolina	35.8	33.3	28.2	25.7	33.3	30.6	32.4	29.9
South Carolina	33.7	32.1	17.5	16.0	28.1	26.7	26.4	24.9
Georgia	18.4	16.0	12.2	10.8	18.5	17.4	16.4	14.7
Alabama	15.2	14.9	17.1	15.7	22.4	22.6	18.2	17.7
Mississippi	....	....	23.0	26.4	38.6	31.9	30.8	29.2
Louisiana	26.5	21.5	36.4	30.9	35.9	30.6	32.9	27.7

CHART 1. **Track in the United States of the Total Eclipse of May 28, 1900.**

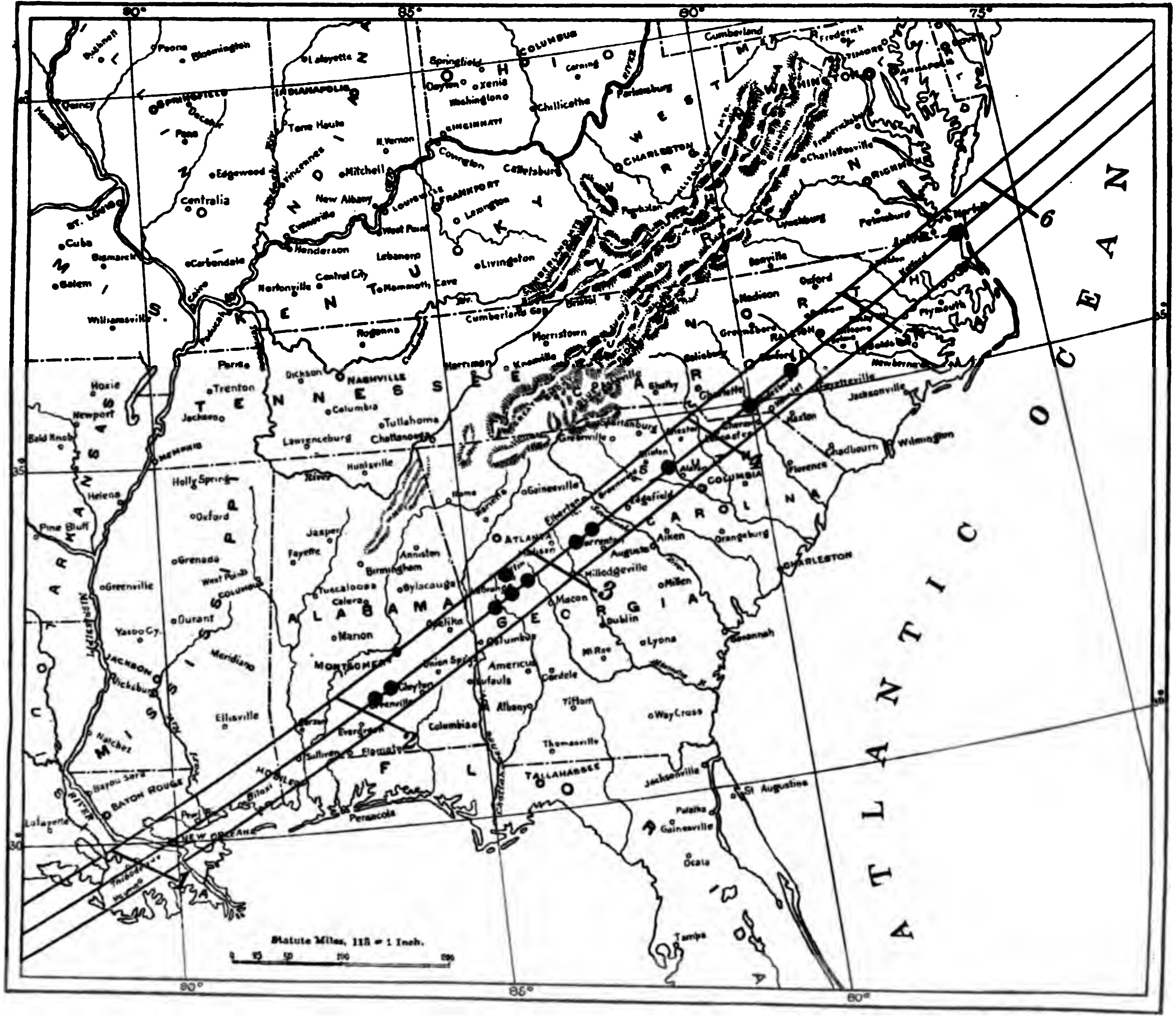
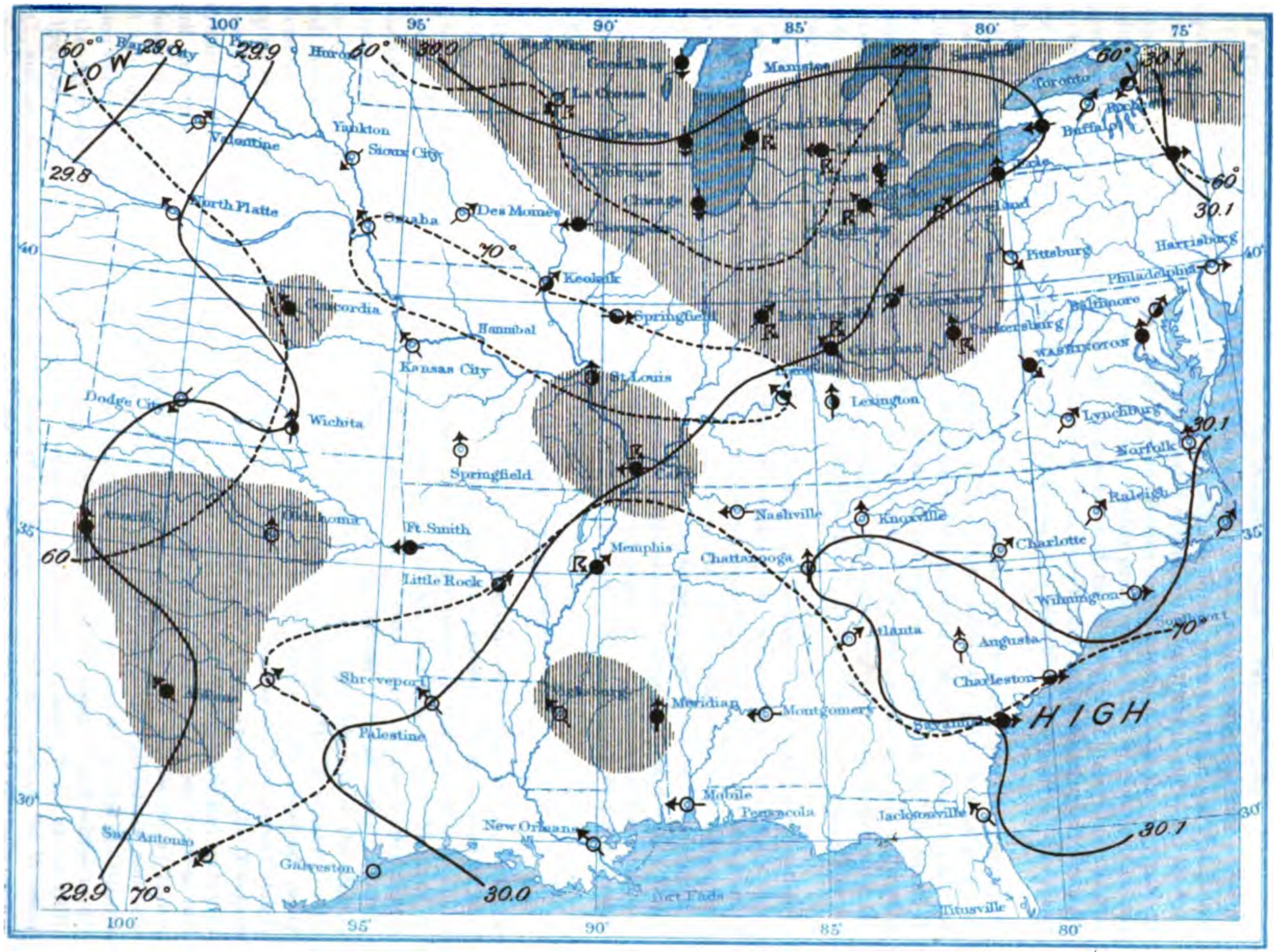


CHART 2.

Weather map showing the conditions at 8 a. m., May 28, 1900.



OBSERVATIONS FOR THE METEOROLOGICAL EFFECTS AND THE SHADOW BANDS.

Further preliminary work was done by the Weather Bureau in two directions.

(1) For the observations on the effect of the passage of the moon's shadow upon the pressure, temperature, and vapor tension of the atmosphere, suitable forms were prepared and distributed to the regular stations of the Weather Bureau located within 500 miles of the moon's total shadow. Fortunately several first-class meteorological observatories were situated within the very path of totality, so that it was not necessary to make any further preparations than to give instructions regarding the reading of the instruments. An account of the discussion of these observatories is to be found in Chapter 2 of this report, where it is shown that the meteorological elements were appreciably affected, and that from the variations it is possible to compute the amount of the heat lost or gained per kilogram of air.

(2) For the observations of the shadow bands a circular was prepared, describing a simple method of observing them, which was distributed along the belt of the path of totality to our regular and volunteer observers, giving them sufficient time before May 28 to admit of all the necessary preparations being made. A full account of the results of this work will be found in Chapter 3. The principal purpose was to decide whether the shadow bands are a diffraction phenomenon, due to the action of the moon's edge on the solar light, or a phenomenon in the earth's atmosphere, and thus strictly a meteorological effect. It seems that the observations are decisive in favor of the latter hypothesis.

Finally the view of the corona, which was obtained at Newberry, S. C., and our studies in the subject of solar physics, suggested the idea of reviewing the recent advances in physics which have a direct bearing upon the meteorological problems, especially those of the transmission of solar energy to the earth's atmosphere and the transformation of this energy within the atmosphere itself. A brief summary of these studies is contained in Chapter 4, and it will be found useful in showing to meteorologists and astronomers generally the status of these important topics, which are now claiming to an unusual degree the attention of physicists. A condensed summary of certain systems of formulæ is also added in Chapter 5, which will be convenient for reference by advanced students in these fields of astrophysical research.

PERSONNEL OF THE EXPEDITION.

By direction of the Chief of the Weather Bureau, I proceeded from Washington, D. C., to Newberry, S. C., on May 22, for the purpose of installing the apparatus. I was joined on May 26 by Prof. CLEVELAND ABBE, whose report on the polarization of the sky will be found elsewhere. Mr. ROBERDEAU BUCHANAN, of the Nautical Almanac Office, Prof. WALTER S. HARSHMAN, of the United States Naval Observatory, Mr. JAMES PAGE, of the United States Hydrographic Office, Mrs. BIGELOW, Mrs. BUCHANAN, the Misses WILKES, Miss LINDSLY, Mrs. HARSHMAN, all of Washington, took the opportunity to view the phenomenon of the eclipse. Prof. GARRETT P. SERVISS, Mr. OTIS WATTLES, Mr. CHARLES LEMBKE, Mr. WALLACE GOOLD LEVISON, of Brooklyn, N. Y., also made observations in Newberry. We received ready hospitality and practical assistance from President GEORGE B. COMERS of Newberry College, from Professors SLEIGH and CANNON, from Dr. HOUSEAL, on whose grounds the Weather Bureau apparatus was located, from Mr. W. T. DAVIS, who supplied the masonry and carpenter work, and from Mr. J. Z. SALTER, who placed his photographic laboratory at our disposal and assisted in taking and developing the photographs. The proprietors of the Newberry House and the superintendent of the Newberry cotton mill also performed several acts of courtesy which were much appreciated. The local press was pleased to record our work, and the citizens of the city assembled one evening to listen to brief lectures on meteorological and eclipse topics by Professors ABBE and BIGELOW. Similar lectures were given at Columbia, S. C., at Rockhill, S. C., and at Charlotte, N. C. In all of these places it was noted that the work of the Weather Bureau seemed to be regarded with much favor, and a growing appreciation of the value of the service was generally pronounced to be the result of the outcome of local experiences. We were indebted on these occasions to the cooperation of Mr. J. W. BAUER, section director at Columbia,

S. C., to Prof. **Cleveland Abbe**, Jr., of the Winthrop Institute, Rockhill, S. C., and to Mr. **John Wilkes**, of Charlotte, N. C. The Southern Railroad also made special arrangements for our accommodation. Our thanks are hereby extended to all those persons who thus contributed to make the expedition pleasant and successful.

THE LOCAL CIRCUMSTANCES AT NEWBERRY, S. C.

The local astronomical circumstances at Newberry were as follows:

Latitude	34°	16′	
Longitude	81°	39′	
	5^h	26^m	36^s
Sun's declination	21°	26′	
Eclipse begins civil G. M. T.	13^h	43^m	
Local M. T.	8^h	$16^m.4$	
75th meridian time	8^h	43^m	

The location of our instruments was about 2 miles north of the central line of totality. The weather was perfectly clear, the sky nearly free from dust and mist, the air was calm with a wind velocity of only 2 or 3 miles per hour, and apparently quiet to great altitudes. This was due to the facts that Newberry is in the midst of the prevailing high-pressure belt, where the west-east circulation is a minimum, and that the pressure conditions were normal on the morning of May 28 when the western portions of the south Atlantic high overspread the Southeastern States. The air was dry and a temperature of 68° F. prevailed at the beginning of the eclipse, falling to 64° a quarter of an hour after totality. No special effort was made to make meteorological observations at Newberry, because these were provided for suitably at other places, and there seemed to be no reason for adding to those records. The wind fell to a dead calm at the time of totality, and the smoke of the neighboring city ascended nearly vertically. On the preceding days it had been drifting quite vigorously in various directions.

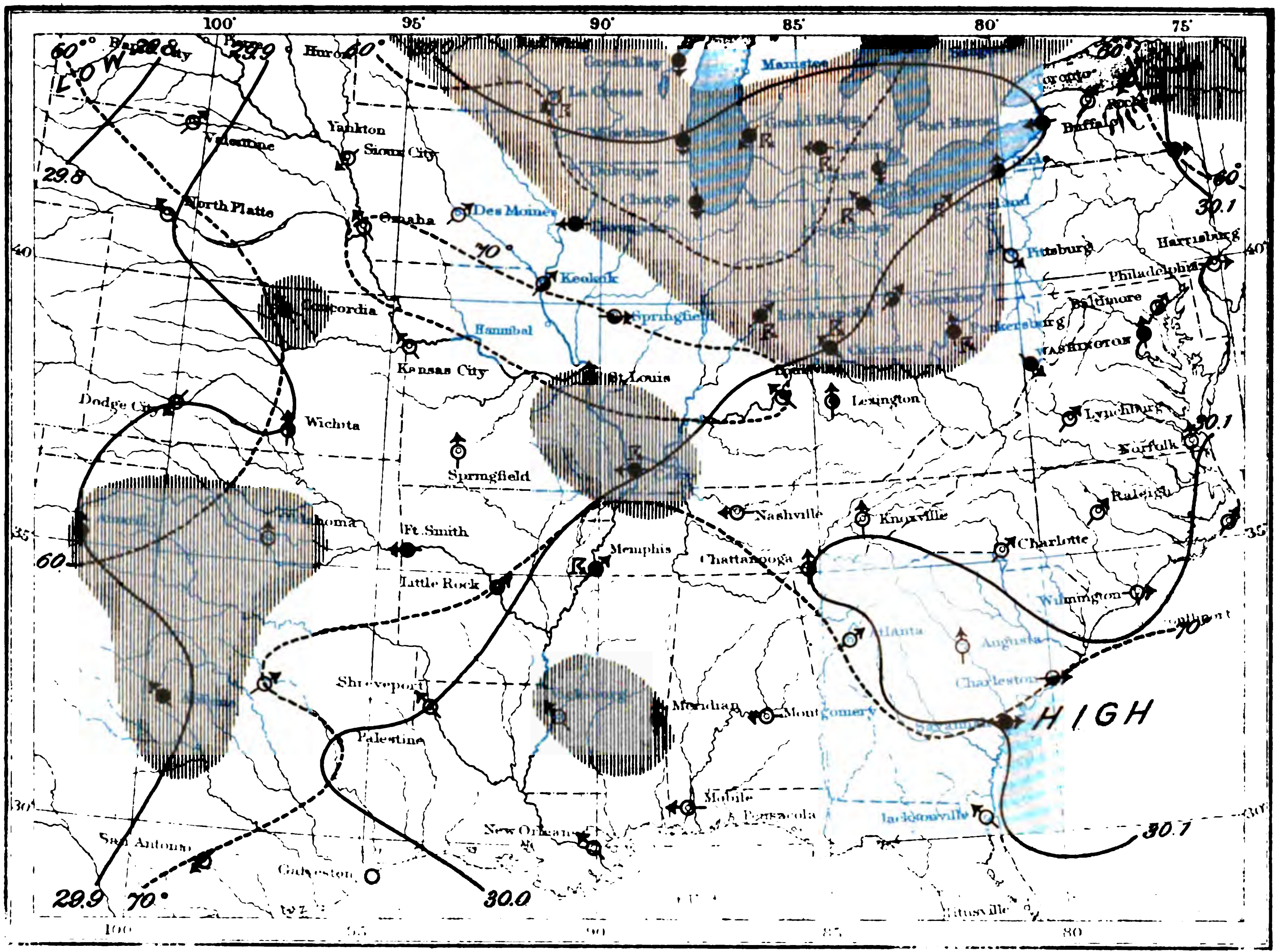
THE PURPOSE OF THE NEWBERRY OBSERVATIONS.

The writer of this report was a member of the United States Eclipse Expedition, which was sent to Cape Ledo, West Africa, to observe the eclipse of December 22, 1889, and it was natural that the experiences of that occasion should suggest the line of work undertaken for May 28, 1900. My duties in connection with the Weather Bureau rendered it impracticable to enter upon as extensive astronomical preparations as would have been desirable, and there was no expectation of being able, with the instrument in my possession, of competing with the magnificent photographs obtained by specialists engaged in astrophysical researches. Indeed, it is becoming plainer every year that the day of the amateur observer of eclipses is passing away, and that the expert knowledge and practice required for the preparation of suitable eclipse apparatus and photographic material can be acquired only by those who devote much time to this class of investigation. Nevertheless, in the development of ideas there is always some preliminary experimenting to be done, and it was on this modest plan that our work was conceived and executed. Its results may be sufficiently suggestive to constitute a proper contribution to the literature of the eclipse.

Photographs of solar eclipses may be divided into two classes: (1) Those which seek to obtain the total effect of the corona, extending continuously from the photosphere of the sun outward into space as far as it is possible to trace it. Such results are obtained by using a plate in the focus of the telescope, whereby all available light is concentrated from the objective on the sensitized film. If long streamers are to be obtained, the disk of the moon covering the sun must be on a small scale, and a telescope having a focal length of 8 or 10 feet, which makes an image of the sun approximately one-half an inch in diameter, is, perhaps, the most successful, though excellent photographs of the details of the outer corona have been made on even a smaller scale than that. (2) On the other hand, if one wants the minute structural details of the inner corona, then it is necessary to enlarge the image of the sun up to 4 inches in diameter and as much more as is practicable. To do this requires a long focus, as, for example, 40 feet for a

CHART 2.

Weather map showing the conditions at 8 a. m., May 28, 1900.



about 2 feet into a dark camera room, through an opening in a house covered with two or three thicknesses of heavy dark canton flannel, and it carried the photographing apparatus which has been described in Astronomy and Astrophysics for April, 1892. The motion of the tube in hour angle was governed by a rod attached to the tube by a ball connection and resting on dry sand in a heavy piston 3 feet long. The sand was drawn off by a special valve, which could be made to regulate the speed by turning a screw so that the fall should be equal to that of the sun. A pair of poles was erected in connection with a rope and pulleys for taking up the weight of the apparatus in preliminary work. We had sufficient help from the *Pensacola* at our disposal, so that it was practicable to employ these methods on that occasion. The hour-angle rod was made in several parts which fitted together, so that the tube could be used near the meridian or down toward the horizon. It is evident that adjustments in azimuth were readily made by following the sun from noon to near sundown, and taking up the variation by altering one end of the base at the anchor irons. Aside from distribution of the weight of the instrument, we have all the essentials of an equatorial telescope of special solidity and stability, since the lower end was held in a grip of iron near the camera and the upper end was braced on a tripod having a spread of 10 feet one way along the polar base, and 30 or 40 feet in both the other directions. As to results, it was found that the definition and steadiness of the sun's image in the dark room was all that could be desired, and that the pictures of the cusps of the sun taken through clouds at the beginning and ending of the eclipse were very satisfactory, promising an admirable performance on the corona. Unfortunately the clouds thickened at the time of the totality and entirely blotted out the corona. The weather had been very good for several afternoons preceding the 22d; but there is every reason to think that it was the presence of the shadow near the seacoast and the accompanying chill which was sufficient to condense the vapor in an atmosphere already at a high relative humidity.

Having this experience and these principles in mind, I was anxious to see how far they could be adapted to use in a short telescope, and at the same time secure a large image of the sun with the surrounding coronal appendage. For it is very evident that a small apparatus producing similar results would be more practicable in field work than the large 40-foot combination used at Cape Ledo. I had at my disposal only a small refractor uncompensated for the photographic rays, 4½ inches aperture and 48 inches focal length, and accordingly my pictures are of little value beyond being a criterion for some important experiments of which others may take advantage. However, it is my conviction that a short-focus apparatus arranged for an enlarged image will become the last product of the evolution of eclipse photographic telescopes.

THE MOUNTING OF A SHORT-FOCUS TELESCOPE FOR ENLARGED IMAGE, AT NEWBERRY, S. C.

The following apparatus was constructed at the Weather Bureau and mounted at Newberry, as shown on Chart 4. Heavy 8-inch posts were sunk in the ground about 4 feet and embedded in broken brick and Portland cement; about 2 feet above the surface they were sawn off in a horizontal plane, as determined by leveling; on this was laid a plank about 6 feet long, with the central line in the geographical meridian; it was clamped to the posts by heavy iron bolts, which, passing through slots in the board, admitted a moderate amount of adjustment in azimuth; over the posts was erected at one end an iron stand to carry the northern end of the polar axis near the telescope; over the southern post was erected a foot iron which admitted an adjustment of the foot-end of the polar axis through several degrees in polar distance, and thus would allow stations having several degrees of difference in latitude to be occupied by the same instrument on different occasions; an extension rod in declination with a turn buckle permitted the adjustment in declination. On Chart 4 is seen the plan of the mounting.

$A =$ the posts sunk in the ground.
$B =$ the horizontal board.
$C =$ the connecting bolts with azimuth adjustments.
$D =$ the polar axis.
$E =$ the northern support.
$F =$ the southern support with adjustment in latitude.

G = the rotation axis with clamp.
H = the rotation foot with bearing.
I = the declination rod with extension buckle.

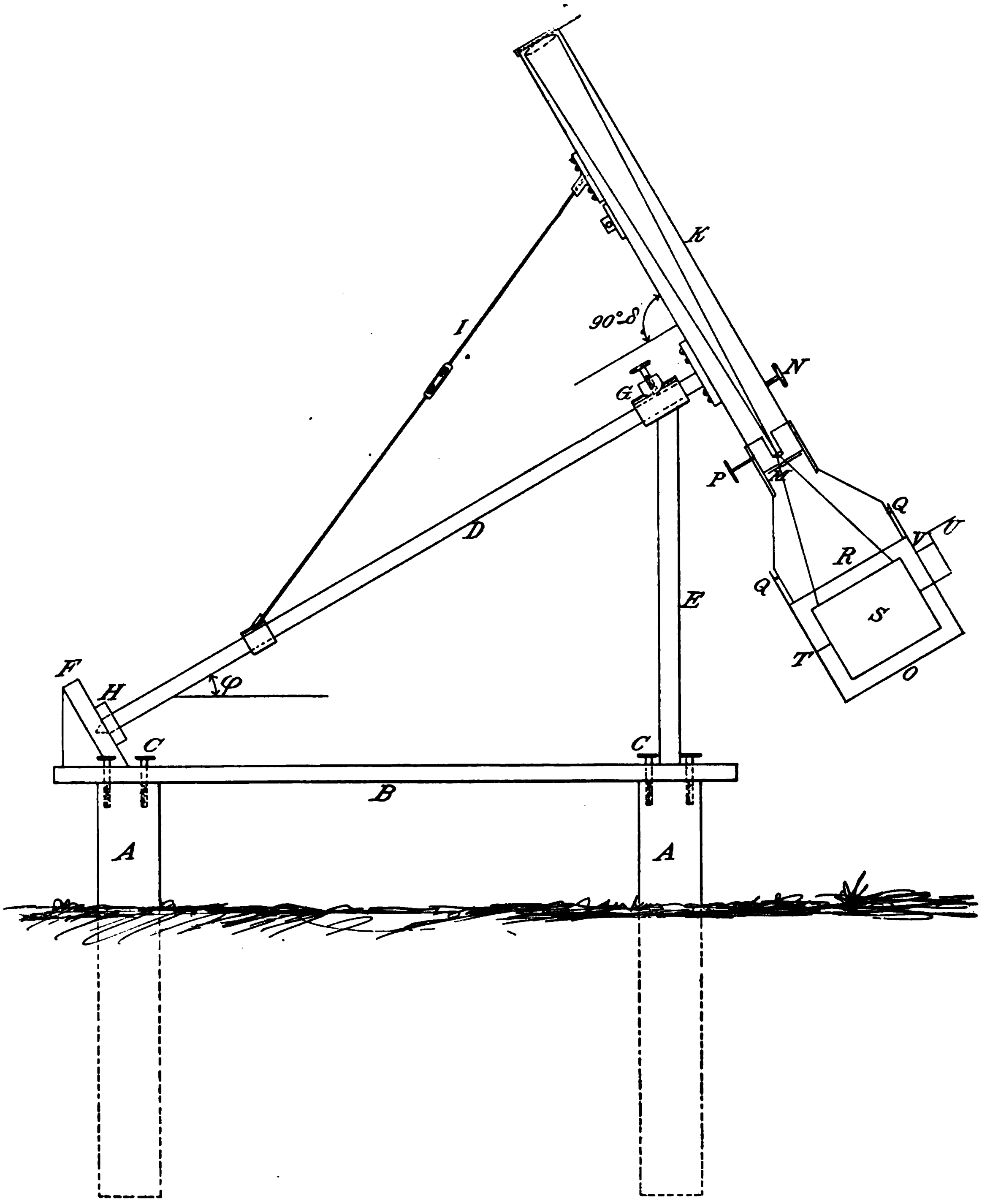


CHART 4.—Mounting of a short-focus telescope for enlarged image, at Newberry, S. C.

Hence, by measuring from the horizontal plane the angle $\varphi=34^\circ\ 16'$ for Newberry, S. C., and the angle $90^\circ-\delta=68^\circ\ 34'$ for May 28, we place the axis of the telescope in the plane of the sun for that date. I succeeded in setting the sun upon the plate of the camera at the first rough adjustment, and could center it perfectly by means of the turn-buckle *I*.

THE CAMERA APPARATUS.

The telescope itself was first inclosed in a square wooden box *K*, just large enough to receive it, as a foundation for the attachment of all required auxiliary apparatus. Upon this was screwed the irons *D* and *I* by appropriate joints. The wooden tube was a little longer than the telescope; upon the upper end was placed a shutter slide *L*, made of a thin copper sheet running in grooves; the lower end was stopped by a block of wood, pierced by a hole large enough to carry the emerging pencil of light, and this was covered by a second aluminum shutter *M*, by which the exposures were made. It ran by the central hole to the blank pieces at each end, and it was drawn across quickly for short exposures, as required. The shutter *L* when closed permitted manipulations at the camera; when *L* was open the shutter *M* alone controlled the exposures; by means of the two entire safety from the external light with speed of operation was always secured. The focusing screw *N* controlled the fine adjustment of the image on the plate. The camera *O* was made in two parts, as it was proposed to operate in the open air, outside of a dark room. A trumpet-shaped connecting piece slid at one end over the telescope box, and thus permitted the large adjustments of the focal plane to be made by slipping it along the tube, after which it was clamped with the screw *P*; the other end opened wide to about 11 inches and then had a short extension parallel to the telescope tube. This carried on two of its sides some brass runners, matching slots *QQ* on the camera box proper. The purpose of this arrangement was to detach the camera entirely from the tube, so that it could be taken away. The camera, therefore, had a closing shutter *R* which when down rendered the plate chamber light-tight, and when drawn up permitted the light to pass into it upon the plate. This chamber contained a square frame *S*, carefully made to hold four 8½ by 6½ plates, which was centered on the axis *T* carrying a handle *U* on one end. By turning the handle to four different points, and fixing it to them in succession by a spring and V-point, the plates were mechanically placed in the focal plane of the telescope. An enlargement of 36 diameters was used, the eyepiece being furnished by G. N. SAEGMULLER, of Washington, D. C. The camera was loaded with the plates in a dark room and the shutter *R* closed; it was then carried to the telescope and placed on the slides *Q*. On drawing the shutter *R* all was ready to operate, by first drawing *L* and then exposing through *M*. This worked on a spring back and forth, and on driving it in one direction a plate was exposed; then *U* was turned to the next hole, at right angles to its first position, and the second exposure was made. This mode of working causes the least possible loss of time for changing the plates, the minimum of jarring, and permits a very perfect regulation of the length of the exposures, from a fraction of a second to any required interval. A second camera was prepared, so that by removing the first and substituting the second, with the loss of a very few seconds another set of four plates was ready for exposure.

The advantage accruing to the exposure of a photographic plate in the focus of a long lens, without any enlargement, is due to the fact that the entire available light is concentrated. The disadvantage is that in the case of the corona the contrast of light is so great between the inner coronal ring and the thin outlying streamers that the inner structure is entirely lost in a general blur on the plate, while the outer rays do not come down at all. In consequence, these large scale pictures, while beautiful, are very featureless. They show the prominences and the average distribution of actinic material, but the coronal details are usually sacrificed. Now, one way to overcome this difficulty in part is to spread out the coronal image by an enlarging lens, and give the exposure more time, to compensate for the thinness of the light. This tends to form the detailed structure much more minutely, and it is my belief that this principle is the proper one to employ in developing the eclipse telescope. On the other hand, an increase in the time of the exposure brings in its train other difficulties to overcome. For a 1-second exposure a clock motion is a subordinate matter, but for one of 10 to 15 seconds it is of primary importance; also, the liability to tremor in the telescope, due to gusts of wind and other causes, renders it imperative that the motion should be communicated in a manner contributing to steadiness and rigidity. The ordinary equatorial mounting, where the telescope is balanced at the center and the driving motion is communicated through a small wheel, is far from being adequate to these requirements. There must be a special device for moving the telescope in hour angle and at the

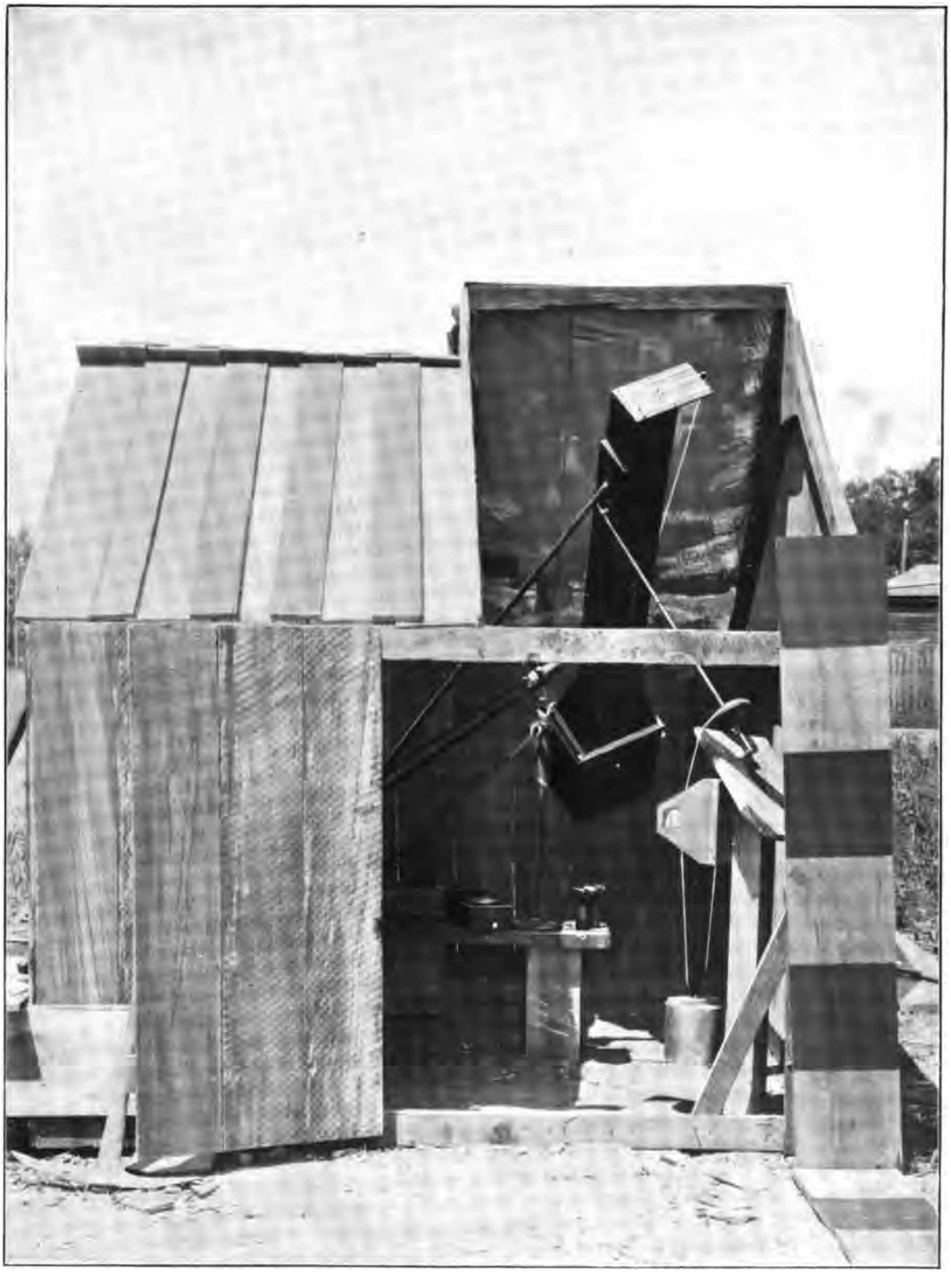


CHART 6.—THE OBSERVER'S HOUSE AT NEWBERRY, S. C., SHOWING THE POSITION OF THE TELESCOPE AND THE AUXILIARY APPARATUS.

same time holding it firmly at every point. The apparatus just described is suitable to secure a true setting and to follow the sun at any hour of the day. What is needed in addition is a short differential time motion lasting through the critical moments of the totality.

THE MOTION IN HOUR ANGLE.

This was secured as follows: The essential features are a rod stretching from the top of a long post, set firmly with cement in the ground, to the upper end of the telescope tube, as shown on Chart 5, or Chart 6. Let the post *A* carry a board *B* inclined at an angle that will be nearly parallel to the direction of the driving rod at the moment of totality. The rod *C* extends from the plate *B* to the tube *D*; at the lower end it terminates in a firm standard, made to move in two planes at right angles to each other, so as to prevent any frictional binding; the upper end runs through a similar two-way standard, and terminates in a good screw for giving the slow motion; it can be readily taken out by a movable clamp cap. This is convenient for quick approximate

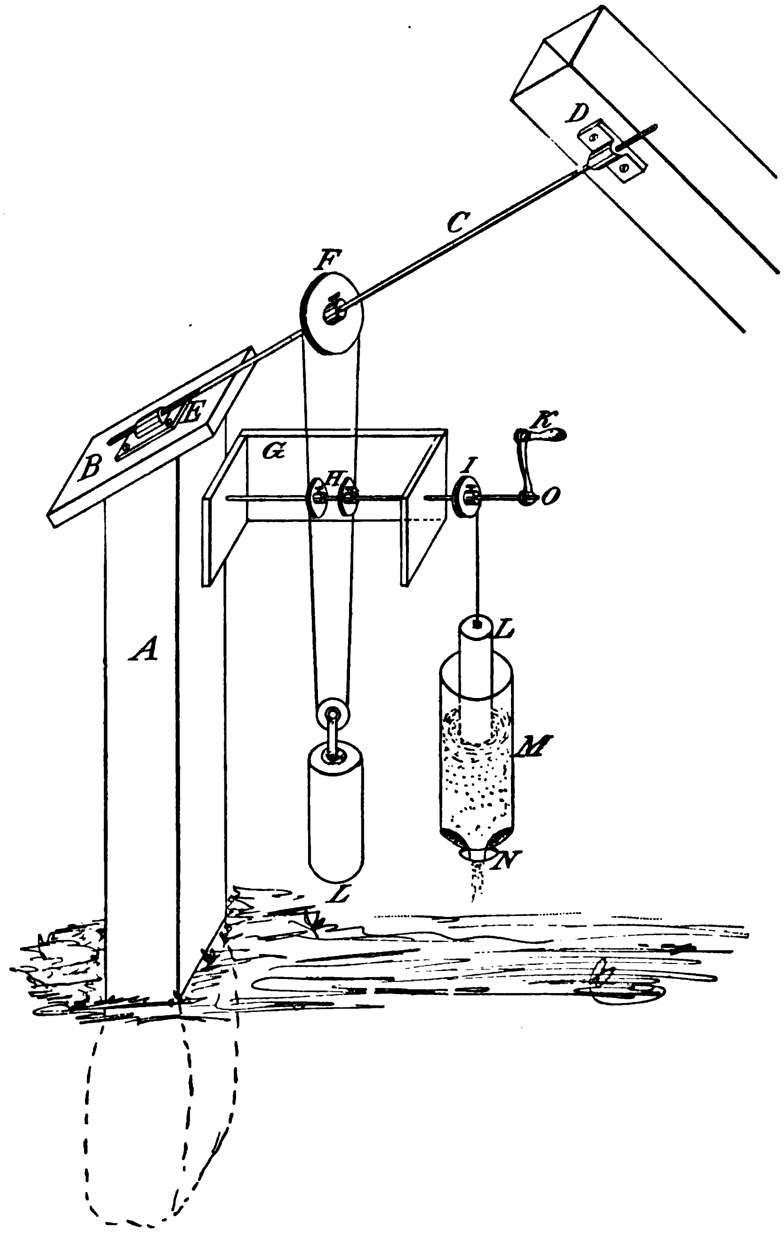


CHART 5.—The apparatus for the movement in hour angle.

adjustment, and for removing the rod entirely from the telescope. The rod carries a grooved wooden wheel *F*, which is adjustable to any position on the rod by a brass hub carrying a set screw. The post also has a frame attached to it on one side; through the center of the frame runs an axle which carries two small wheels *H*, both adjustable along the axis by clamp-screw hubs; outside the frame this axle carries a small wheel *I*, and a turning handle *K*; an endless cord is now wound over *F* and *HH*, and continues to a stretching weight *L*, which keeps it taut. Upon *I* is wound a cord which is attached to a piston weight *L*; this rests upon sand in a piston *M*, and the flow of the sand is regulated by the conical valve *N*. The wheel *I* is clamped to the axle *O* by a clamp thumbscrew, so that it can be detached readily or set in the proper place when the weight *L* is needed for working. The handle *K* is useful for quick motion, and for preliminary experimental work. Indeed, a skillful hand on the handle *K* is sufficient for imparting a very steady motion to the telescope tube, by making so many turns per minute. Of course the dimensions are all relative and depend upon the telescope. Any form of driving the rod *F* may be substituted for this contrivance, as a good clockwork on the other side of the post *A*, operating directly upon the rod *DB* extending beyond the inclined plate. The essential feature is that the bearings at *E* and *D* should be firm, and as frictionless as good workmanship can secure, all the other parts being of secondary importance. This rod also supports the telescope at its upper end, and guards it against all vibrations from the wind; also, it stops very quickly the tremors produced by changing the plates at the camera. I was much pleased with the working of the instrument, and believe that for portability, ease of installation, and steadiness of operation in all kinds of weather it is practical and efficient.

THE PHOTOGRAPHIC RESULTS.

My photographs were not very important because of using an uncorrected lens, so that it was not possible to obtain a clear sharp actinic focus. The run in 10 seconds was about 2 millimeters, and this amount of motion must be given to the telescope by the rotation of the driving rod. It was not possible to know before the eclipse the proper time exposures in order to obtain results from the corona with an enlargement of 36 diameters. The image on the plate was 8 centimeters, or 3¼ inches; the coronal rays extend to 1.5 centimeters, or six-tenths of an inch; that is, about one-third the solar radius. Several prominences were observed on various portions of the limb. The first and second plates were lost by an underexposure of 1 and 4 seconds, respectively; the exposure of 8 seconds brought down the inner corona in full, and that of 12 seconds began to blacken the inner portions. An exposure of 10 seconds was about right. Hence, where 2 seconds would be enough in the focus of a long lens, 10 seconds were required for this enlargement. It is perfectly practicable to obtain four plates of 10 seconds exposure during the first minute of the eclipse; the change to a second camera can be made in 15 seconds; thus, in an eclipse of average duration, at least eight long exposure plates ought to be made with such a telescope. I have been explicit in giving the details of the mounting, as it will save others who may wish to try this plan some preliminary investigations, and it is most important to have a clear idea of the main features of the work before beginning operations.

The aspect of the corona, as seen at Newberry, showed that it consisted of a bright inner ring of light-yellow color, and then spread out in pearly sheets finely striated with lines. The polar rays were distinctly detached from one another; the equatorial wings were irregularly widened in a fish-tail shape on the preceding side, and contracted in a conical shape on the following side. Further remarks on the corona are to be found in Chapter 4.

The preparations for observing the shadow bands consisting in laying down a long canvas oriented to the points of the compass, and in preparing two boards painted alternately in black and white foot spaces, by means of which the width of the bands might be estimated; also two sticks were at hand ready to lay down on the sheet parallel to the bands. Nothing was seen of the bands before totality began; as the totality was ending faint shadows an inch or two wide flitted over the sheet, and their direction was marked. Generally the phenomenon was disappointing, and the fact that it was inconspicuous is attributed to the remarkably quiet state of the atmosphere above the place. This subject will be discussed in Chapter 3.

GENERAL REMARK.

We may make one general remark regarding the relation of preliminary meteorological surveys to the selection of sites for eclipse stations. To simply determine the average conditions as to temperature, humidity, and relative cloudiness, on such a day as might be expected for the eclipse is really misleading, if the conclusion stops there. The temperature during the eclipse drops from 4° to 8° F., and this chill of the atmosphere is often enough to produce a cloud stratum in what would otherwise be a clear sky. If the humidity averages high enough to condense when the temperature falls a few degrees, the site is unfit for observations. This is often the case on the coast in tropical countries and on islands, so that these are likely to be unsuitable for purposes of observation. There are several instances of failure of eclipse expeditions due to this cause alone. It is better to seek an inland station at some considerable elevation, if possible, and then the task of transporting heavy instruments becomes a serious difficulty. An efficient light-weight apparatus is therefore a very great desideratum.

CHAPTER 2.

THE METEOROLOGICAL CHANGES CAUSED BY THE SHADOW OF THE MOON DURING THE ECLIPSE.

THE PREPARATION FOR THE SPECIAL METEOROLOGICAL OBSERVATIONS.

By direction of the Chief of the Weather Bureau a form was prepared for recording the meteorological observations required for determining the influence of the shadow of the moon in its passage through the earth's atmosphere. These records contain accurate readings of the barometer, the wet and dry bulb thermometers, the direction and velocity of the wind, and the amount of cloudiness. The method of observing is precisely that practiced by the observers of the United States Weather Bureau in their regular line of duty. The instruments were all standard and the corrections were properly applied, so that the resulting data are first class in every particular. Since the instruments and method of observing have been suitably described in the reports of the Weather Bureau and are already well known, it is not necessary to make any further preliminary remarks regarding the character of the observations themselves. The unusual advantage pertaining to this eclipse was the fact that it passed over a region so well supplied with meteorological instruments and observers that it was not considered important to make any further preparations than to provide suitable forms for recording the readings taken at certain specified times.

Thus we had such stations as New Orleans, Raleigh, Norfolk, Mobile, Charlotte, and Montgomery located directly in the path of totality, and better equipped than it would be possible to provide by any temporary installments in control of eclipse parties in the field. It also gave us an excellent opportunity to eliminate the specific effect of the shadow cone from the diurnal range by including a large number of stations located outside the path of the totality. There has always been much uncertainty in ascribing to the shadow its own proper effect, because it was not known how far the diurnal range on that occasion varied from the mean diurnal range in the several elements. In order to eliminate the shadow effect from the diurnal range it was decided to examine a wide belt on each side of the total-eclipse path, and accordingly all our stations within 500 miles of the central line were included in the programme. We have, therefore, reports from 62 stations, covering quite uniformly a belt 1,000 miles wide, through the midst of which the shadow passed, and the following data are compiled from this large group of reporting stations. Fortunately the weather was very propitious for such observations, since the atmospheric conditions were practically quiescent except on the extreme northern border of this wide belt, so that only very slight cyclonic conditions were superposed upon the diurnal variation. By taking the records extending from Texas to New England and from the Ohio Valley to the Gulf of Mexico it is certain that the mean variations on May 28, 1900, must have been practically free from any important cyclonic movements, so that any other variation caused by the shadow would be clearly defined as such and attributable only to that cause.

The observations were assigned to certain minutes in the following way: The time of maximum obscuration was computed for all the stations, including those within and those outside the shadow path; then an observation was assigned to that instant, others to the next 5 minutes later and earlier, and others at intervals of 15 minutes backward and forward, so that the entire number of separate observations was 25 for each station. The observers were requested to continue the observations hourly if convenient till night, but as only a few complied the record is restricted to those grouped uniformly about the central hour of maximum obscuration.

TABLES OF THE VARIATION OF THE METEOROLOGICAL CONDITIONS OF THE ATMOSPHERE.

The following tables, 3 to 9, have been compiled from the original records of the observations. They assume the value of the atmospheric element as observed at the moment of totality or greatest obscuration to be the *normal* value from which the variations are computed, and these are found for all the stations in Table 3, which gives the pressure, temperature, vapor tension, wind velocity and direction, and the observed cloudiness at that instant for each of the 62 stations.

Since the variation on itself must be zero at totality, this is entered as .000 under the thirteenth column of Table 4, and likewise in Tables 5, 6, and 7, and is also marked "total." The variations are reckoned backward and forward by subtracting this central value from those observed at the several minutes of the observations before and after totality. The times of totality are given in the last column of Table 3. The algebraic sum of the time there given, which is seventy-fifth meridian, and the intervals beginning —165^m in column 1 and ending +150^m in column 24 of the several tables, gives the seventy-fifth meridian time at which the local observations were made. Since the important point to be secured by the observations is the relative effect of the passage of the moon's shadow through the earth's atmosphere, it is obvious that this arrangement of the data brings out the required result with a minimum of computation.

The stations are arranged in the order of their distance in miles from the center of the shadow path; they are marked N. for north and S. for south, to distinguish on which side of it they are located. The first group contains the 6 stations which are within or on the very edge of the shadow, and so must have received the full influence of the meteorological effect. It is properly these to which the computations for any physical variation on the elements should be applied, and yet the partial phase up to 500 miles from the center involved an obscuration of at least nine-tenths of the light of the sun, so that all these stations ought to be influenced almost as much as the central group. By extending the compilation to so many stations situated on the north and south, and along the line of the eclipse from east to west, the mean values of the groups tend to eliminate the local cyclonic conditions prevailing at that hour. Since the lapse of time between the first and the last minute of totality in the United States is only 53 minutes—that is, from 8.24 at Corpus Christi to 9.17 at Eastport, the range in the ordinary diurnal variation can be neglected, especially during the early forenoon hour when the progression is steady and not changed by any maximum or minimum occurring at that time. The stations are divided into groups, and the means are taken.

Then the 62 stations occurring in the 9 groups are collected in a general mean at the end, and by inspection one can scrutinize the variations of any group or of any single station from this average value. The mean time of all the stations for the instant of the average mean or central totality is 8^h 47^m 30^s, seventy-fifth meridian time. In order to display the significance of these variations in the several groups and for the general mean, the data of Tables 4 to 8 inclusive have been transferred to Charts 7 to 11 respectively. These give the variations in the barometric pressure, the temperature, the vapor tension, the wind velocity, and the wind azimuth in succession. The following remarks therefore depend upon this exhibit of the meteorological data, and they are readily verified by the reader from an inspection of the charts.

THE BAROMETRIC PRESSURE.

The trend of all the barometric variation lines of Chart 7 is upward to higher pressures with the lapse of time. Since the mean time of totality is 8^h 47^m, this increase is in conformity with the course of the diurnal range, as may be seen by consulting Chart 44, International Cloud Report, page 466, at the latitude 40° and for the hour 9 a. m. Since the eclipse extended to about 10.30 a. m., the falling off from the morning maximum is just about to set in, and this is shown by the drop in the curves from number 19, which is $1^h\ 15^m$ after the totality. An inspection of these curves for evidences of characteristic changes in the pressure due to the effect of the moon's shadow shows that there may be a slight rise at Nos. 15, 16, that is 15 to 30 minutes past totality, with drops at Nos. 10, 11 and Nos. 17, 18; but this is very uncertain, and the mean curve is so smooth that this can not be positively asserted. There can be a variation of only a very few thousandths of an inch when the average of any large number of good barometers is taken. From the action of the pressure at individual stations there might be drawn some other conclusions regarding these pressure changes, which would yet be quite erroneous as regards the same when all local modifications are eliminated by using many station records. It was evidently such individual local variations which must have been used by Mr. H. H. CLAYTON in forming his theory regarding the effect of the moon's shadow on the pressure of the atmosphere.*

TABLE 3.—*The meteorological data at the several stations for the moment of totality from which the variations were computed.*

Stations	Pressure	Temperature	Vapor tension	Wind	Clouds		Total	
							h.	*m.*
New Orleans	29.966	76.0	.783	3 SE.	1 S. Cu.	S.	8	31
Raleigh	29.712	71.1	.432	4 SW.	1 Ci.	W.	8	49
Norfolk	30.008	68.5	.448	5 S.	....	....	8	53
Mobile	30.005	72.8	.732	3 NE.	3 Cu.	E.	8	33
Charlotte	29.285	67.0	.402	8 SW.	1 Ci.	W.	8	46
Montgomery	29.844	72.0	.595	1 E.	1 S.	....	8	37
Means	**29.803**	**71.2**	**.565**	**4 S.**	**1**	**SW.**		
Atlanta	28.892	68.8	.432	8 SW.	1 A. S.	W.	8	40
Pensacola	30.000	74.0	.732	12 E.	3 Cu.	E.	8	33
Meridian	29.668	71.1	.684	3 S.	2 S. Cu.	SW.	8	35
Kitty Hawk	30.089	63.0	.448	1 S.	....	....	8	53
Hatteras	30.118	65.6	.448	2 SW.	....	....	8	51
Lynchburg	29.329	66.5	.481	2 SW.	1 Ci.	....	8	51
Wilmington	30.021	68.9	.417	6 W.	......	....	8	46
Galveston	29.918	77.2	.732	0	2 S. Cu.	SE.	8	27
Charleston	30.091	70.1	.432	7 W.	6 Ci.	NW.	8	44
Atlantic City	30.027	56.7	.417	6 S.	1 Ci. S.	N.	8	59
Corpus Christi	29.937	75.0	.732	4 S.	1 Cu.	S.	8	24
Chattanooga	29.317	64.3	.417	1 S.	1 S. Cu.	NW.	8	41
Vicksburg	29.770	71.6	.684	5 SE.	1 A. Cu.	SW.	8	34
Savannah	30.052	69.3	.481	5 W.	8 Ci. S.	W.	8	40
Knoxville	29.064	66.0	.481	6 S.	1 A. S.	SW.	8	44
Washington	29.933	63.8	.387	4 S.	10 S.	W.	8	55
Baltimore	29.921	68.0	.373	3 SW.	7 Ci. Cu.	W.	8	56
Nantucket	30.171	47.8	.310	19 NE.	10 S.	NE.	9	08
Philadelphia	29.957	64.8	.481	6 E.	7 A. Cu.	NW.	8	59
Block Island	30.156	50.3	.310	23 NE.	10 S.	NE.	9	05

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*The Eclipse Cyclone and the Diurnal Cyclones. H. Helm Clayton, Ann. Harv. Coll. Obsy., Vol. XLIII, Part 1, 1901.

Proceedings of the American Academy of Arts and Sciences, Vol. XXXVI, No. 16, January, 1901.

Discussion of these papers, Science, March 1, April 12, and May 10, 1901.

Table 3.—*The meteorological data at the several stations for the moment of totality from which the variations were completed*—Continued.

Stations	Pressure	Temperature.	Vapor tension.	Wind.	Clouds.		Total.	
							h.	*m.*
New York	29.791	55.8	.387	27 NE.	10 S.	NE.	9	02
New Haven	30.060	52.4	.298	14 NE.	10 S.	NE.	9	04
Jacksonville	30.062	73.1	.536	6 E.	1 A. Cu.	SW.	8	38
Harrisburg	29.663	65.0	.402	4 W.	8 A. Cu.	W.	8	58
San Antonio	29.256	70.0	.684	......	4 S. Cu.	SE.	8	26
Nashville	29.481	70.2	.536	3 E.	6 A. Cu.	SW.	8	42
Shreveport	29.744	71.8	.660	4 SW.	1 A. S.	S.	8	32
Boston	30.126	48.0	.246	10 N.	10 S.	NE.	9	08
Palestine	29.446	69.2	.638	6 S.	Clear		8	30
Parkersburg	29.389	64.0	.499	2 SE.	10 A. S.	SW.	8	51
Lexington	28.989	66.8	.536	7 S.	3 A. Cu.	W.	8	47
Memphis	29.628	72.2	.616	10 SW.	4 A. S.	SW.	8	38
Pittsburg	29.148	71.0	.448	5 NW.	1 Ci. Cu.	....	8	55
Little Rock	29.634	70.0	.638	3 S.	8 Ci. Cu.	SW.	8	36
Albany	30.057	56.6	.277	9 S.	10 S. Cu.	W.	9	05
Louisville	29.464	70.3	.555	4 S.	4 A. Cu.	W.	8	46
Binghamton	29.145	62.1	.432	6 NW.	4 A. S.	W.	9	01
Portland	30.170	48.0	.180	11 NE.	6 A. S.	NE.	9	10
Cincinnati	29.335	66.5	.555	8 N.	10 N.	NW.	8	48
Cairo	29.638	67.3	.638	4 SE.	4 A. S.	SW.	8	41
Tampa	30 029	74.0	.660	5 E.	10 A. Cu.	SW.	8	33
Columbus	29.154	65.8	.481	5 SW.	3 A. S.	W.	8	51
Eastport	30.193	47.0	.245	3 N.	1 S.	W.	9	17
Northfield	29.281	50.3	.334	5 S.	10 N.	S.	9	08
Cleveland	29.186	62.5	.448	5 NE.	10 S. Cu.	SW.	8	54
Erie	29.276	65.0	.465	6 SW.	10 S. Cu.	SW.	8	56
Oswego	29.711	56.2	.417	5 N.	2 A. S.	W.	9	02
Indianapolis	29.129	63.3	.517	14 S.	5 S. Cu.	W.	8	48
Rochester	29.507	63.0	.432	5 N.	1 Ci.	W.	9	00
Sandusky	29.317	62.0	.499	4 S.	10 A. S.	SW.	8	53
Buffalo	29.213	66.0	.448	6 E.	10 S. Cu.	SW.	8	59
Abilene	28.100	68.0	.555	9 SE.	4 Ci.	W.	8	29
St. Louis.	29.370	74.0	.575	5 S.	3 A. Cu.	W.	8	42
Jupiter	30.025	76.2	.707	9 NE.	10 S.	NE.	8	34
Springfield	28.759	65.6	.595	6 S.	4 A. Cu.	SW.	8	39
Key West	29.993	75.8	.707	7 E.	2 A. S.	SE.	8	29
Means	**29.641**	**65.0**	**.502**					

TABLE 4.—*Pressure variations during the total eclipse of May 28, 1900.*

[Referred to the pressure at the moment of totality.]

Station	Dist. Cent.	1 -165	2 -150	3 135	4 -120	5 -105	6 -90	7 75	8 -60	9 45	10 30	11 -15	12 -5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
1. New Orleans	0	-.022	.014	-.016	-.013	-.012	-.013	.008	.004	-.001	.000	+.001	+.001	.000	+.001	+.005	+.005	+.010	+.013	+.011	+.007	+.011	+.005	+.003	+.005
Raleigh	6 N	-49	-47	-36	-32	30	24	21	-17	-14	10	-7	3	.000	+2	-5	-4	-5	-1	-1	-3	-7	-10	-10	-13
Norfolk	15 N	27	-34	24	-21	20	-17	12	12	-10	-9	-7	-1	.000	-3	1	1	-2	+5	+5	+7	+7	+1	3	+3
Mobile	25 S	-24	26	-25	-23	-24	22	20	-15	13	-2	0	0	.000	0	-6	8	....	....	....	....	....	....	....	....
Charlotte	25 N	34	-28	-28	-25	-19	-18	-11	7	5	2	-1	0	.000	+4	+3	+4	+1	+6	+6	+5	+5	+6	+5	+3
Montgomery	27 N	-14	9	-6	-9	-5	-3	-2	+2	+1	+3	+3	0	.000	+2	+8	+7	+6	+10	+12	+6	+5	+1	-3	+1
Means	**16**	**-28**	**-26**	**-23**	**-21**	**-18**	**-16**	**12**	**9**	**-7**	**-3**	**2**	**-1**	**.000**	**+1**	**+1**	**+1**	**+2**	**+7**	**+7**	**+4**	**+4**	**+1**	**-2**	**0**
2. Atlanta	40 N	26	-25	25	23	20	-15	-11	-9	-8	-4	5	0	.000	0	0	0	4	-1	+2	+4	+2	0	0	-1
Meridian	95 N	-27	-20	16	-11	-10	-7	7	-5	-2	+2	-5	+1	.000	+3	+2	+2	+1	-1	+2	+4	+3	+3	+4	0
Lynchburg	110 N	19	-19	-18	-18	-10	-9	-9	+5	+6	+3	+1	+1	.000	0	0	+6	+6	+7	+7	+8	+7	-4	-9	-16
Galveston	125 N	-29	-29	27	-27	-24	-22	-20	19	-15	-3	3	2	.000	0	+12	+13	+2	+1	+1	+2	+2	+5	+7	+7
Atlantic City	135 N	-29	-19	23	-25	9	12	-13	9	+3	+1	+1	0	.000	+6	+12	+9	+19	+29	+30	+38	+41	+37	+39	+34
Corpus Christi	140 N	-35	-35	35	-33	-29	-26	-21	18	14	10	5	-1	.000	+1	+4	+8	+10	+14	+16	+16	+14	+13	+10	+9
Chattanooga	140 N	-32	-28	-22	-22	-17	-9	-6	-7	5	4	-2	2	.000	1	0	+1	+1	-1	-1	0	0	-1	2	-3
Vicksburg	155 N	-32	26	-27	-28	-20	19	-17	-14	-15	12	-7	-1	.000	0	0	+1	+2	+1	....	....	-5	-7	-9	....
Knoxville	160 N	-29	-28	11	11	-9	-8	-4	4	4	3	-1	0	.000	+1	+1	+1	+1	+1	+5	+5	+2	-5	-5	7
Washington	160 N	-26	-24	-23	-19	-12	7	0	+1	0	2	+3	+4	.000	+7	+7	+13	+19	+26	+24	+24	+22	+20	+16	+12
Baltimore	180 N	-34	-29	-11	-18	-13	-9	-6	5	4	3	-2	-1	.000	+1	+2	+3	+6	+8	+9	+9	+10	+10	+8	+8
Nantucket	180 N	-73	-57	-44	-40	-32	32	-27	21	18	-9	5	-4	.000	+3	+4	+7	+17	+23	+26	+27	+32	+32	+39	+47
Philadelphia	190 N	-40	-36	-32	-30	-31	-28	24	23	-20	-16	7	-3	.000	+1	+6	+17	+24	+25	+29	+32	+33	+34	+36	+39
Means	**139**	**-33**	**-29**	**-24**	**-23**	**-18**	**-16**	**13**	**-10**	**-7**	**-5**	**-3**	**-1**	**.000**	**+2**	**+4**	**+6**	**+8**	**+10**	**+13**	**+14**	**+13**	**+11**	**+10**	**+11**
3. Block Island	210 N	-58	-56	-48	-44	-31	-18	13	-8	8	-3	+1	-2	.000	0	+2	+9	+13	+16	+25	+28	+31	+39	+40	+42
New York	220 N	-42	-33	-20	-24	-23	-7	+5	+10	+5	+2	+1	0	.000	+6	+11	+14	+20	+39	+42	+42	+43	+44	+43	+54
New Haven	240 N	-57	46	42	-34	-22	25	18	-19	18	8	-3	0	.000	+1	+5	+7	+13	+16	+22	+23	+29	+32	+34	+42
Harrisburg	260 N	24	-29	27	-22	-21	18	11	7	0	0	+8	+5	.000	+5	+3	+8	+12	+20	+20	+14	+20	+21	+22	+23
San Antonio	260 N	-46	-44	-42	-43	-36	23	26	30	-30	-22	-20	-12	.000	+2	11	12	10	-11	-9	11	11	12	12	14
Nashville	260 N	10	-9	-8	-5	-5	3	3	1	1	+1	+2	+1	.000	0	1	-4	-5	7	6	+2	+6	+11	+14	+15
Shreveport	260 N	25	-22	-19	-14	-12	-8	11	11	-11	-5	-4	-3	.000	+2	+4	+1	+4	+6	+13	+11	+4	+5	+1	+6
Boston	280 N	-63	-53	51	46	-47	-43	27	-19	11	-11	-5	-2	.000	1	+2	-1	+4	+8	+16	+17	+24	+26	+28	+32
Means	**249**	**-41**	**-37**	**-32**	**-29**	**-25**	**18**	**-13**	**11**	**-10**	**-6**	**-3**	**-2**	**.000**	**+2**	**+2**	**+3**	**+6**	**+11**	**+15**	**+16**	**+18**	**+21**	**+21**	**+25**
4. Palestine	300 N	-16	13	-20	-7	+2	5	0	+3	+6	+6	+6	0	.000	+10	+16	+14	+16	+15	+19	+25	+26	+26	+23	+16
Parkersburg	300 N	10	7	-3	-2	0	+1	+3	+3	+4	+11	+16	+4	.000	+4	+5	+7	+9	+9	+11	+11	+12	+13	+14	+14
Lexington	300 N	-17	-14	-13	-15	-18	-14	13	11	9	3	-1	0	.000	+1	+2	+2	+2	+1	-4	0	+5	+3	+7	+4
Memphis	300 N	-37	36	-35	-32	-30	-26	25	18	16	8	-7	0	.000	2	-2	-8	+2	+3	+3	+4	+9	+9	+12	+7
Pittsburg	335 N	29	-29	-18	16	-18	11	16	6	5	5	0	0	.000	+1	+6	+1	-2	+2	+2	+5	+2	5	-8	-10
Little Rock	340 N	-23	23	-18	-18	-16	16	20	-10	-10	-6	-6	0	.000	0	+4	+4	+9	+5	+5	+10	+15	+15	+20	+20
Albany	345 N	-49	-44	-24	-23	-11	-10	-11	10	5	-6	-4	-1	.000	-1	-1	+7	+14	+14	+28	+31	+32	+34	+49	+50
Louisville	350 N	-9	-8	-8	-12	-14	-15	-9	-10	-9	-4	-3	-3	.000	1	3	-2	-5	-6	-7	-9	-9	-10	6	-7

TABLE 4.—*Pressure variations during the total eclipse of May 28, 1900*—Continued.

Station.	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +130
4. Binghamton	350 N	−13	−13	−2	+20	+24	+24	+25	+23	+16	+11	+3	−5	.000	+1	−1	−1	+10	+12	+13	+8	+1	−1	+7	−1
Portland	360 N	−65	−62	−54	−45	−36	−38	−35	−21	−22	−13	−3	−4	.000	+3	+7	+11	+16	+18	+15	+14	+4	+4	+1	+5
Cincinnati	370 N	−8	+2	−8	−18	−11	−2	+5	+13	+13	+13	+8	0	.000	+3	+7	+10	+20	+30	+34	+29	+19	+29	+19	+39
Cairo	380 N	−17	−10	−2	−5	−10	−9	−10	−7	−8	−5	−4	0	.000	+1	+1	0	−1	+1	+4	+6	+10	+9	+7	+4
Columbus	380 N	−23	−22	−17	−8	+3	−2	−2	−2	−2	+1	+1	0	.000	0	+1	+4	+5	+4	+7	+12	+18	+19	+23	+27
Eastport	390 N	−7	−7	−6	−3	−2	−1	+2	+4	+4	+2	+3	+2	.000	−1	−1	−1	−1	−1	0	0	+1	+1	0	−2
Means	**348**	**−23**	**−20**	**−16**	**−18**	**−10**	**−9**	**−8**	**−4**	**−3**	**0**	**0**	**0**	**.000**	**+1**	**+2**	**+3**	**+7**	**+8**	**+9**	**+10**	**+10**	**+10**	**+12**	**+12**
5. Northfield	425 N	−51	−43	−41	−34	−29	−22	−18	−18	−16	−11	−5	−2	.000	+1	+6	+11	+19	+21	+27	+28	+34	+42	+48	+42
Cleveland	445 N	+11	+14	+14	+14	+12	+17	+16	+14	+15	+12	+5	+5	.000	−1	+1	+3	+16	+9	+10	+14	+25	+30	+36	+42
Erie	450 N	−42	−40	−39	−38	−34	−32	−23	−7	−3	+3	+3	0	.000	−1	−2	0	+4	+13	+19	+24	+24	+15	+4	+3
Oswego	450 N	−23	−22	−21	−21	−19	−17	−14	−12	−8	−3	−2	0	.000	0	+7	+10	+16	+21	+21	+21	+21	+23	+27	+28
Indianapolis	450 N	−10	+4	−17	−18	+24	+13	0	−1	−8	−4	−3	+4	.000	−6	0	−7	−14	+23	+27	+25	+27	+24	+27	+27
Rochester	460 N	−40	−36	−38	−32	−32	−28	−22	−12	−9	−6	−5	−5	.000	0	0	+3	+3	+3	+11	+18	+9	+8	+8	+13
Sandusky	465 N	0	−2	−1	−2	−1	−2	−11	−12	16	−21	−17	−12	.000	+6	+9	+27	+31	+33	+35	+38	+39	+41	+43	+43
Buffalo	465 N	−19	−23	−20	−10	−10	−11	−14	−4	+4	0	+1	−1	.000	0	+1	+8	+16	+18	+22	+24	+30	+31	+32	+33
Abilene	470 N	−5	−13	−13	−15	−15	−15	−18	−13	−8	−8	−4	0	.000	0	−1	+1	+5	+23	+22	+22	+16	+19	+19	+18
St. Louis	500 N	−13	−10	−9	−10	−8	−7	−7	−9	−10	−10	−5	−2	.000	0	−2	0	−2	0	+2	−1	0	−2	−1	−1
Springfield, Mo.	520 N	−23	−21	−21	−24	−25	−24	−21	−19	−11	−7	−4	−6	.000	+2	−1	0	+3	+4	+5	+9	+10	+11	+11	+10
Means	**464**	**−20**	**−17**	**−19**	**−17**	**−12**	**−12**	**−12**	**−8**	**−6**	**−5**	**−3**	**−2**	**.000**	**0**	**+2**	**+5**	**+9**	**+15**	**+18**	**+20**	**+21**	**+22**	**+23**	**+23**
6. Pensacola	65 S	−34	−32	−24	−22	−21	−20	−10	−6	−5	−2	−4	−1	.000	+1	+1	+7	+9	+10	+10	+11	+13	+15	+14	+12
Kitty Hawk	100 S	−52	−42	−45	−40	−37	−17	−14	−15	−15	−15	−10	−10	.000	+10	+3	+3	−10	−10	0	+10	+4	+7	+7	+7
Hatteras	100 S	−51	−44	−41	−36	−27	−20	−16	−17	−18	−11	−11	−1	.000	0	+12	+12	+12	+12	+16	+19	+17	+17	+17	+20
Means	**88**	**−46**	**−39**	**−37**	**−33**	**−28**	**−19**	**−13**	**−13**	**−13**	**−9**	**−8**	**−4**	**.000**	**+4**	**+5**	**+7**	**+4**	**+4**	**+9**	**+13**	**+11**	**+13**	**+13**	**+13**
7. Wilmington	110 S	−26	−27	−24	−23	−20	−13	−9	−11	−7	−4	−1	−1	.000	+5	+6	+8	+10	+10	+13	+14	+15	+14	+12	+9
Charleston	125 S	−33	−33	−25	−24	−24	−16	−3	−5	−5	−3	−3	−1	.000	+2	+10	+10	+12	+17	+17	+23	+20	+17	+14	+13
Savannah	158 S	−27	−21	−20	−22	−20	−16	−10	−9	−5	0	−2	0	.000	+1	+4	+7	+13	+14	+17	+17	+22	+24	+25	+25
Means	**131**	**−29**	**−27**	**−23**	**−23**	**−21**	**−15**	**−7**	**−8**	**−6**	**−2**	**−2**	**−1**	**.000**	**+3**	**+7**	**+8**	**+12**	**+14**	**+16**	**+18**	**+19**	**+18**	**+17**	**+16**
8. Jacksonville	240 S	−33	−32	−31	−25	−22	−18	−9	−4	−4	−6	−3	0	.000	+3	+3	+3	+5	+10	+13	+17	+16	+17	+13	+11
Tampa	380 S	−26	−26	−25	−25	−20	−14	−8	−4	−6	−6	−2	0	.000	+4	+8	+8	+9	+9	+4	+6	+3	+3	+1	−1
Means	**310**	**−30**	**−29**	**−28**	**−25**	**−21**	**−16**	**−8**	**−4**	**−5**	**−6**	**−2**	**0**	**.000**	**+4**	**+6**	**+6**	**+7**	**+10**	**+8**	**+12**	**+10**	**+10**	**+7**	**+5**
9. Jupiter	500 S	−34	−32	−28	−25	−23	−19	−17	−18	−13	−7	−6	−4	.000	+1	+2	+2	+6	+7	+5	+3	+10	+12	+13	+13
Key West	600 S	−36	−30	−32	−33	−29	−27	−33	−25	−24	−8	−5	−5	.000	−4	−4	−2	+3	+4	+6	+4	+2	+4	+6	+8
Means	**550**	**−35**	**−31**	**−30**	**−29**	**−26**	**−23**	**−25**	**−22**	**−18**	**−8**	**−6**	**−4**	**.000**	**−2**	**−1**	**0**	**+4**	**+6**	**+6**	**+4**	**+6**	**+8**	**+10**	**+10**
Means	....	−29	−26	−23	−21	−17	−14	−11	−8	−7	−4	−2	−1	.000	+1	+3	+4	+7	+10	+12	+13	+13	+13	+14	+14
Shadow variations	....	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.001	−.003	−.005	−.006	−.002	.000	.000	.000	.000	.000	.000

CHART 7.

Barometric pressure variations.

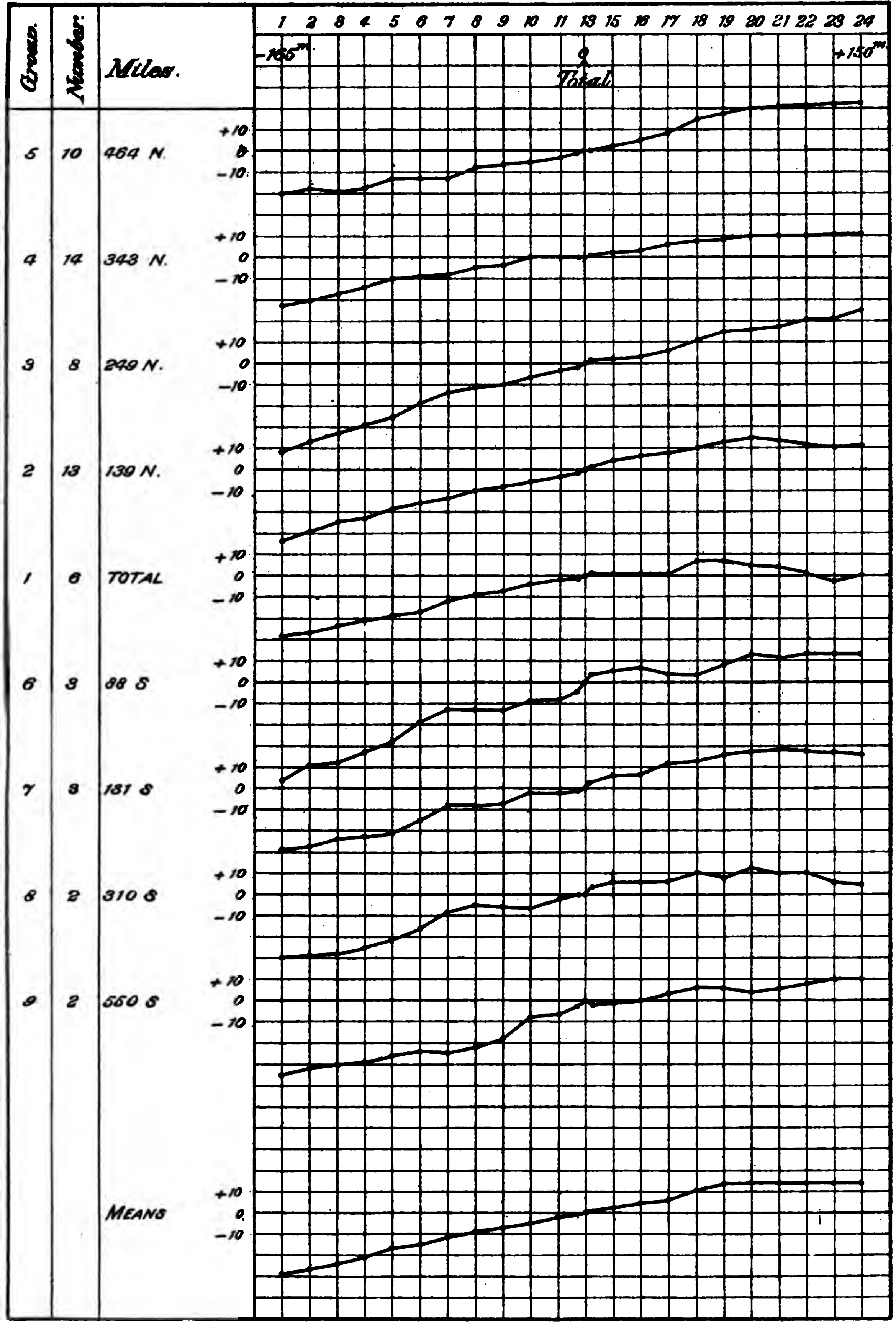


TABLE 5.—*Temperature variations during the total eclipse of May 28, 1900.*

[Referred to the temperature at the moment of totality.]

Station.	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total.	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
1. New Orleans	0	−0.6	−0.8	−1.0	−1.0	−0.9	−0.4	+1.0	+1.5	+0.5	+0.5	+0.5	0.0	0.0	0.0	0.0	+0.6	+2.0	+2.0	+4.0	+5.0	+6.3	+6.3	+6.3	+5.1
Raleigh	6 N	−6.7	−5.8	−4.9	−4.3	−5.1	−4.9	−3.1	−1.7	−0.6	−0.5	−0.3	−0.8	0.0	−1.4	−1.7	−1.6	−0.1	+1.4	+3.4	+5.9	+8.4	+8.9	+9.9	+10.8
Norfolk	15 N	−8.8	−9.0	−7.5	−6.3	−5.7	−4.0	−2.4	−1.5	−0.2	+0.9	+0.5	+0.1	0.0	−0.3	−0.5	−1.0	−0.3	+1.5	+4.3	+6.0	+6.5	+6.7	+8.0	+9.0
Mobile	25 S	−2.0	−2.0	−2.3	−1.8	−1.8	−1.8	−1.3	+0.2	+1.2	+0.7	0.0	+0.2	0.0	0.0	+0.2	+0.2	+0.2	+1.2	+3.2	+5.2	+4.2	+6.2	+6.2	+8.2
Charlotte	25 N	−7.2	−6.5	−5.0	−5.0	−3.0	−2.0	−0.8	+0.3	+1.3	+1.5	+1.0	+0.5	0.0	0.0	0.0	+0.8	+1.5	+3.5	+4.9	+6.0	+7.0	+7.0	+8.5	+10.0
Montgomery	27 N	−4.5	−4.4	−3.7	−2.4	−1.9	−1.0	+1.1	+1.0	+1.0	+2.0	+2.5	0.0	0.0	0.0	0.0	+1.5	+2.0	+3.5	+5.5	+5.5	+7.5	+8.5	+8.5	+9.0
Means	**16**	**−5.0**	**−4.8**	**−4.1**	**−3.5**	**−3.1**	**−2.4**	**−0.9**	**0.0**	**+0.5**	**+0.9**	**+0.7**	**0.0**	**0.0**	**−0.3**	**−0.3**	**+0.1**	**+0.9**	**+2.2**	**+4.2**	**+5.6**	**+6.7**	**+7.3**	**+7.9**	**+8.7**
2. Atlanta	40 N	−4.3	−4.0	−3.7	−3.2	−2.2	−1.4	−0.2	+1.1	+1.2	+1.0	+0.4	0.0	0.0	−0.5	−0.8	+0.2	+0.8	+2.2	+3.0	+4.4	+6.1	+6.4	+6.7	+6.7
Meridian	95 N	−2.8	−3.9	−3.0	−2.7	−1.8	−1.7	−1.7	−0.1	+0.4	+0.9	+0.6	+0.2	0.0	0.1	−0.2	+0.6	+2.0	+3.9	+3.3	+4.9	+5.9	+7.0	+7.4	+8.3
Lynchburg	110 N	−9.5	−9.0	−7.3	−5.5	−5.0	−3.0	−1.5	+1.3	+2.3	+2.2	+2.5	+0.5	0.0	−0.5	0.0	+0.9	+2.6	+3.5	+5.5	+10.0	+10.0	+10.5	+14.5	+14.0
Galveston	125 N	−1.4	−1.3	−1.3	−1.2	−1.0	−1.0	−0.7	+0.6	+2.0	+1.9	+0.8	+0.2	0.0	0.0	+0.2	+0.7	+2.3	+2.5	+2.0	+2.1	+3.9	+3.3	+1.9	+3.6
Atlantic City	135 N	+1.9	+2.0	+1.1	+1.3	+1.5	+1.3	+1.7	+1.6	+1.6	+0.3	+0.6	+0.3	0.0	−0.2	0.0	+0.6	+1.8	+2.3	+3.5	+3.3	+2.8	+3.5	+3.3	+4.3
Corpus Christi	140 N	−1.0	−1.0	−1.0	−1.0	−1.5	−2.0	−1.0	0.0	+1.0	+0.8	+1.0	0.0	0.0	0.0	0.0	+0.5	+2.0	+3.0	+4.2	+4.0	+4.6	+4.1	+4.2	+4.5
Chattanooga	140 N	−6.3	−6.3	−6.1	−5.3	−4.9	−4.3	−3.2	−2.3	−0.3	+1.4	+1.7	+0.4	0.0	−0.1	+0.4	+0.4	+1.7	+5.7	+5.9	+7.9	+9.5	+9.3	+11.2	+11.8
Vicksburg	155 N	−1.5	−1.5	−1.6	−2.0	−1.8	−1.3	−0.6	+0.3	+0.6	+0.7	+0.4	+0.2	0.0	0.0	0.0	+0.5	+1.6	+2.7	+3.7	+4.6	+5.6	+6.0	+6.4	+7.1
Knoxville	160 N	−6.9	−7.0	−5.7	−4.7	−3.8	−2.6	−1.7	−0.5	+0.4	+0.5	+0.3	0.0	0.0	0.0	−0.4	+1.3	+2.0	+2.8	+4.5	+7.0	+8.8	+10.8	+11.2	+12.0
Washington	160 N	−1.8	−1.5	−0.8	−0.3	+1.2	+0.7	+0.4	+0.7	+0.4	+1.0	+0.4	+0.2	0.0	+0.2	+0.2	+0.7	+2.2	+2.5	+3.7	+4.2	+4.4	+5.2	+5.6	+6.2
Baltimore	180 N	−3.0	−3.0	−3.2	−3.9	−2.0	−3.0	−1.0	−1.0	−0.9	−0.4	0.0	0.0	0.0	0.0	+0.5	+0.5	+0.5	+1.0	+2.5	+3.5	+4.3	+4.0	+5.0	+7.0
Nantucket	180 N	+1.5	+1.5	+1.3	+1.3	+1.2	+1.2	+1.1	+0.2	+0.4	0.0	0.0	+0.2	0.0	−0.3	+0.1	+0.4	+0.7	+0.2	+0.2	+0.2	+1.0	+1.4	+0.7	+1.0
Philadelphia	190 N	−4.1	−3.8	−2.5	−0.7	−0.3	+2.5	+3.0	+3.3	+4.0	+3.2	+1.2	+0.2	0.0	−0.8	−0.8	−0.8	−0.2	−0.4	−0.1	+1.0	+1.7	+3.6	+2.9	+2.3
Means	**139**	**−3.0**	**−3.0**	**−2.6**	**−2.1**	**−1.6**	**−1.1**	**−0.4**	**+0.4**	**+1.0**	**+1.0**	**+0.8**	**+0.2**	**0.0**	**−0.2**	**−0.1**	**+0.5**	**+1.5**	**+2.5**	**+3.2**	**+4.4**	**+5.3**	**+5.8**	**+6.2**	**+6.8**
3. Block Island	210 N	+0.7	−0.3	−0.3	−0.5	−0.3	−0.3	+0.7	+0.7	+0.5	+0.7	+0.2	−0.1	0.0	0.0	+0.3	+0.7	+0.9	+1.3	+1.7	+1.7	+1.7	+2.7	+1.9	+1.8
New York	220 N	+3.2	+2.7	+3.0	+2.0	+2.2	+1.5	+1.5	+0.7	+0.4	+0.7	+0.5	+0.2	0.0	+0.3	+0.7	+1.2	+1.5	+1.7	+2.2	+2.7	+3.7	+4.6	+4.7	+3.7
New Haven	240 N	+1.8	+2.6	+2.9	+3.6	+3.8	+4.4	+3.7	+3.8	+3.9	+2.6	+0.4	+0.3	0.0	−0.2	0.0	+0.3	+0.8	+0.8	+0.7	+1.6	+2.4	+2.3	+2.5	+1.6
Harrisburg	260 N	−3.0	−2.8	−3.0	−1.5	−0.7	−1.9	−1.5	−0.2	−1.0	−1.0	−0.5	0.0	0.0	0.0	0.0	0.0	+0.5	+2.0	+3.0	+4.0	+6.5	+6.0	+7.0	+7.6
San Antonio	260 N	−2.0	−2.0	−2.0	−2.0	−1.8	−1.5	−0.6	−0.6	+0.2	+0.8	+1.2	+0.5	0.0	0.0	+0.5	+1.0	+2.5	+2.0	+3.1	+4.0	+4.0	+5.0	+4.0	+5.3
Nashville	260 N	−7.2	−6.8	−5.4	−5.2	−4.4	−4.2	−3.8	−2.7	−1.7	−0.7	−0.5	−0.2	0.0	+0.4	+1.0	+1.8	+2.0	+6.3	+6.8	+7.3	+9.0	+6.8	+8.2	+7.4
Shreveport	260 N	−3.9	−3.9	−3.8	−3.6	−3.5	−3.6	−1.8	−0.8	−0.1	+0.6	+0.3	+0.1	0.0	−0.4	+0.3	+0.6	+2.7	+4.2	+4.2	+5.2	+6.5	+6.6	+7.9	+6.9
Boston	280 N	−0.2	+0.3	0.0	+0.3	+1.0	+0.2	+0.8	+0.4	0.0	0.0	+0.9	0.0	0.0	0.0	0.0	0.0	−1.0	−0.5	−0.6	−1.0	−1.0	−0.5	−0.7	−0.4
Means	**249**	**−1.3**	**−1.3**	**−1.1**	**−0.9**	**−0.5**	**−0.7**	**−0.1**	**+0.2**	**+0.3**	**+0.5**	**+0.3**	**+0.1**	**0.0**	**0.0**	**+0.4**	**+0.7**	**+1.2**	**+2.2**	**+2.6**	**+3.2**	**+4.1**	**+4.2**	**+4.5**	**+4.2**
4. Palestine	300 N	−1.0	−1.2	−2.2	−1.8	−1.2	−1.2	−0.6	+0.8	+0.8	+0.9	+0.8	+0.2	0.0	−0.2	−0.2	−0.6	−0.1	+0.7	+1.8	+3.5	+4.1	+5.0	+5.2	+5.8
Parkersburg	300 N	−2.7	−2.0	−2.0	−1.5	−1.2	−1.2	−1.0	−1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+0.4	+0.5	+0.8	+3.0	+5.0	+6.0	+7.0	+9.0	+9.0
Lexington	300 N	−5.8	−5.6	−5.5	−5.2	−4.2	−3.5	−2.3	−2.0	−0.8	+0.8	+1.0	+0.2	0.0	0.0	0.0	+0.9	+1.2	+3.6	+6.4	+7.4	+10.0	+8.7	+9.2	+8.8
Memphis	300 N	−1.2	−1.0	−1.2	−1.3	−1.2	−1.2	−0.9	−0.4	−0.2	−0.2	−0.2	0.0	0.0	0.0	0.0	+0.8	+0.3	−0.2	0.0	+0.3	+0.8	+0.6	+1.0	−0.2
Pittsburg	335 N	−6.0	−4.0	−6.0	−5.0	−4.0	−2.0	−2.0	−1.0	0.0	+1.0	−1.0	+1.0	0.0	−0.5	−1.0	−1.0	0.0	0.0	+1.0	+1.5	+1.5	+3.0	+2.5	+2.0
Little Rock	340 N	−4.0	−3.5	−4.0	−4.0	−3.0	−2.0	−1.0	−0.5	+2.0	+2.0	+1.0	0.0	0.0	−0.2	0.0	+0.8	+1.5	+2.0	+2.5	+2.7	+2.5	+2.5	+3.2	+3.0
Albany	345 N	+2.7	+0.9	+0.9	+1.2	+0.4	+0.9	+0.6	+0.6	+0.6	+0.6	−0.1	−0.2	0.0	−0.2	−0.3	−0.1	−0.4	+0.3	+0.6	+1.5	+1.5	+3.4	+2.2	+1.8
Louisville	350 N	−6.5	−6.4	−6.3	−5.3	−5.0	−3.4	−1.4	−0.4	+0.6	+1.2	+1.2	+0.7	0.0	−0.1	−0.3	+0.4	+1.7	+2.7	+4.7	+4.5	+6.3	+6.3	+6.3	+6.7

TABLE 5.—*Temperature variations during the total eclipse of May 28, 1900*—Continued.

Station.	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total.	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
4. Binghamton	350 N	−1.9	−1.1	−1.6	−1.3	−1.1	−1.1	−1.5	−0.4	+0.9	+0.3	+0.3	+0.2	0.0	−0.1	+0.5	+0.5	+1.9	+2.9	+4.7	+6.9	+7.6	+7.4	+8.2	+11.4
Portland	360 N	+1.0	+1.0	+1.0	+1.0	+1.0	+1.2	+0.5	+0.7	+0.8	+1.0	+1.0	+0.5	0.0	0.0	0.0	+0.5	+0.5	+2.2	+4.0	+4.0	+3.0	+4.0	+3.5	+3.0
Cincinnati	370 N	−1.5	−1.5	−2.0	−2.5	1.8	−1.5	−1.0	−0.7	−0.5	+0.5	+0.5	0.0	0.0	−0.5	+0.4	+0.3	+0.5	+0.5	+0.5	+0.5	+1.5	+1.5	+0.5	0.0
Cairo	380 N	0.0	−0.1	−1.3	−2.0	−1.2	+0.5	+0.4	+0.4	+0.8	+0.7	+0.6	+0.1	0.0	+0.1	+0.4	+0.5	+1.0	+1.4	+2.7	+3.2	+4.6	+5.4	+5.9	+7.6
Columbus	380 N	−5.3	−5.4	−4.7	3.5	−2.2	−0.6	−0.6	−0.8	−0.4	+0.1	+0.2	+0.1	0.0	+0.3	+0.2	+0.5	+1.0	+3.3	+3.3	+2.4	+2.7	+3.1	+3.1	+3.2
Eastport	390 N	−5.0	−4.0	−3.0	−1.5	1.0	0.0	+0.5	+0.5	+1.0	+1.0	+1.0	+0.5	0.0	0.0	+0.5	+1.0	+1.0	+2.0	+3.5	+2.5	+2.0	+3.0	+3.5	+5.0
Means	**343**	**−2.7**	**−2.4**	**−2.7**	**2.3**	**−1.8**	**−1.1**	**−0.7**	**−0.3**	**+0.4**	**+0.7**	**+0.5**	**+0.2**	**0.0**	**−0.1**	**0.0**	**+0.4**	**+0.8**	**+1.6**	**+2.8**	**+3.3**	**+3.9**	**+4.4**	**+4.5**	**+4.0**
5. Northfield	425 N	+3.2	+3.2	+3.7	+3.5	+3.0	+2.7	+2.7	+3.7	+2.2	+1.5	+0.2	0.1	0.0	0.0	−0.1	−0.3	0.0	0.0	−0.3	−0.5	−0.8	−1.3	−1.3	−0.5
Cleveland	445 N	−2.7	−2.2	−2.2	−2.2	−1.7	1.8	−1.2	−0.9	−0.5	−0.3	+0.3	+0.3	0.0	−0.4	−0.4	−1.5	−2.3	−1.6	−0.8	−0.1	−0.1	+0.4	+0.6	+0.8
Erie	450 N	−2.7	−2.4	−2.2	−2.1	−2.0	−1.7	−1.0	−0.4	+0.3	+0.4	+0.4	+0.1	0.0	−0.1	−0.4	−0.5	−0.5	−0.2	−0.4	−0.8	−1.0	0.0	−0.1	+0.4
Oswego	450 N	+1.9	+2.6	+3.6	+2.7	+2.5	+3.7	+4.3	+4.4	+4.1	+4.4	+2.7	+2.0	0.0	+0.2	+0.9	+2.6	+1.7	+2.2	+3.5	+6.0	+6.1	+4.0	+4.3	+5.0
Indianapolis	450 N	−0.5	+0.7	+0.7	−0.1	−1.7	−1.3	−1.1	−0.3	+0.5	+1.0	+0.7	0.5	0.0	−0.5	−0.2	−0.1	+1.4	−0.3	−0.3	−0.3	−1.3	−0.2	+0.1	+0.7
Rochester	460 N	−0.8	+1.0	+2.2	+3.0	+4.0	+4.7	+5.3	+3.3	+0.9	+2.0	+1.1	0.0	0.0	−0.2	−0.3	−2.0	−1.5	−0.5	+1.6	+1.4	+6.4	+5.3	+5.7	+6.4
Sandusky	465 N	−2.0	−1.5	−1.7	−1.9	−1.8	−1.4	−1.2	−0.2	+0.1	+0.3	+0.3	0.0	0.0	0.0	−0.5	−0.4	+0.6	+1.0	+0.4	+0.4	+0.5	+1.0	+1.2	+1.1
Buffalo	465 N	−4.2	−4.5	−4.2	−4.0	−2.7	−1.5	−0.5	−0.2	0.0	0.0	+0.2	+0.1	0.0	+0.2	+0.3	+1.0	+2.1	+0.8	+1.8	+2.0	+2.8	+1.9	+3.2	+5.1
Abilene	470 N	−3.2	−2.4	−2.0	−1.8	1.0	−0.5	0.0	+0.2	+0.7	+0.9	+1.0	+0.4	0.0	0.0	+0.1	+0.1	+1.0	+2.5	+3.8	+6.0	+6.0	+7.0	+7.2	+7.5
St. Louis	500 N	−3.0	−3.1	−3.0	−2.0	1.5	1.0	−0.8	+0.2	+0.6	+1.0	+0.5	0.0	0.0	−0.4	−0.2	−0.1	+0.5	+1.0	+1.0	+2.0	+2.2	+3.0	+3.4	+4.7
Springfield, Mo.	520 N	3.0	−2.8	−2.7	−2.6	−2.6	−1.7	−0.8	−0.5	+0.4	+0.1	+0.6	−0.6	0.0	+0.3	+0.3	+1.1	+1.7	+2.7	+3.4	+5.3	+6.5	+6.7	+6.4	+7.0
Means	**464**	**−1.5**	**−1.0**	**−0.7**	**−0.7**	**0.3**	**0.0**	**+0.5**	**+0.8**	**+0.8**	**+1.1**	**+0.7**	**+0.2**	**0.0**	**−0.1**	**0.0**	**0.0**	**+0.4**	**+0.7**	**+1.0**	**+1.9**	**+2.5**	**+2.5**	**+2.8**	**+3.5**
6. Pensacola	65 S	−3.0	−2.9	−2.2	−1.8	0.3	+0.2	+0.2	+0.7	+0.5	0.0	+0.2	0.0	0.0	−0.2	−0.1	+0.5	+1.5	+3.0	+3.2	+3.6	+4.3	+5.0	+5.5	+6.0
Kitty Hawk	100 S	−4.0	2.0	−1.0	0.0	0.0	0.0	0.0	+1.0	+1.0	+1.0	+1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	+1.0	+1.0	+2.0	+2.0	+3.0	+3.0
Hatteras	100 S	−3.6	2.4	−1.6	−0.6	+0.2	+0.4	+1.6	+1.9	+2.4	+1.6	+0.9	+0.4	0.0	−0.6	−1.6	−1.0	+0.7	+3.4	+5.4	+6.2	+6.6	+5.9	+5.2	+4.7
Means	**88**	**3.5**	**−2.4**	**−1.6**	**−0.8**	**0.0**	**+0.2**	**+0.6**	**+1.2**	**+1.3**	**+0.9**	**+0.7**	**+0.1**	**0.0**	**−0.3**	**0.6**	**−0.2**	**+0.7**	**+2.1**	**+3.2**	**+3.6**	**+4.3**	**+4.3**	**+4.6**	**+4.6**
7. Wilmington	110 S	7.9	−7.5	−6.9	−6.1	4.9	−2.9	−1.9	−0.9	+0.1	+0.5	+0.5	+0.1	0.0	−0.5	−0.7	−0.7	+0.1	+1.1	+2.1	+4.3	+4.9	+6.4	+7.8	+8.7
Charleston	125 S	−4.7	4.1	3.3	−2.7	−2.4	−1.6	−0.4	−0.1	+0.8	+0.8	+0.7	+0.2	0.0	−0.1	−0.1	+0.1	+1.5	+3.5	+5.1	+6.7	+6.7	+8.6	+11.3	+11.3
Savannah	158 S	−6.3	−5.3	−4.6	−3.7	−2.3	−0.9	−0.3	+0.2	+0.7	+1.0	+0.8	+0.5	0.0	0.0	−0.3	+0.5	+2.0	+3.2	+3.7	+4.9	+6.4	+7.2	+8.2	+9.2
Means	**131**	**−6.3**	**−5.6**	**−4.9**	**−4.2**	**−3.2**	**−1.8**	**−0.9**	**−0.3**	**+0.5**	**+0.8**	**+0.7**	**+0.3**	**0.0**	**−0.2**	**−0.4**	**0.0**	**+1.2**	**+2.6**	**+3.6**	**+5.3**	**+6.0**	**+7.4**	**+9.1**	**+9.7**
8. Jacksonville	240 S	−5.7	−5.1	−4.3	−1.9	1.1	+0.1	+0.1	+0.2	+0.7	+0.9	+0.8	+0.7	0.0	0.1	+0.2	+1.5	+1.6	+2.7	+3.1	+2.9	+3.7	+4.5	+4.1	+6.0
Tampa	380 S	−2.9	2.9	−2.9	−2.0	2.0	−2.0	−1.9	−1.0	−1.0	−0.5	0.0	0.0	0.0	−0.5	0.0	+1.0	+2.0	+2.0	+2.2	+4.0	+4.1	+5.5	+6.0	+7.0
Means	**310**	**−4.3**	**4.0**	**−3.6**	**−2.0**	**−1.6**	**−1.0**	**−0.9**	**−0.4**	**0.2**	**+0.2**	**+0.4**	**+0.4**	**0.0**	**−0.3**	**+0.1**	**+1.3**	**+1.8**	**+2.4**	**+2.7**	**+3.5**	**+3.9**	**+5.0**	**+5.1**	**+6.5**
9. Jupiter	500 S	−0.2	0.2	+0.4	+0.5	+0.6	+0.8	+0.8	+0.8	+0.8	+0.6	+0.5	+0.3	0.0	0.0	+0.3	+1.3	+3.6	+3.0	+3.6	+4.0	+4.3	+3.8	+3.8	+4.8
Key West*	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Means	......	−2.8	−2.5	2.3	−1.9	1.4	−0.9	−0.3	+0.2	+0.6	+0.8	+0.6	+0.2	0.0	−0.1	0.0	+0.4	+1.0	+1.9	+2.7	+3.6	+4.4	+4.8	+5.1	+5.4
Shadow variations	......	......	......	......	......	......	......	......	......	0.0	0.0	−0.9	−1.9	−2.2	−2.4	−3.1	−3.4	−3.3	−2.8	−1.4	−0.6	0.0	0.0	......	......

*A local rain occurred which rendered the record inapplicable.

CHART 8.

Temperature variations.

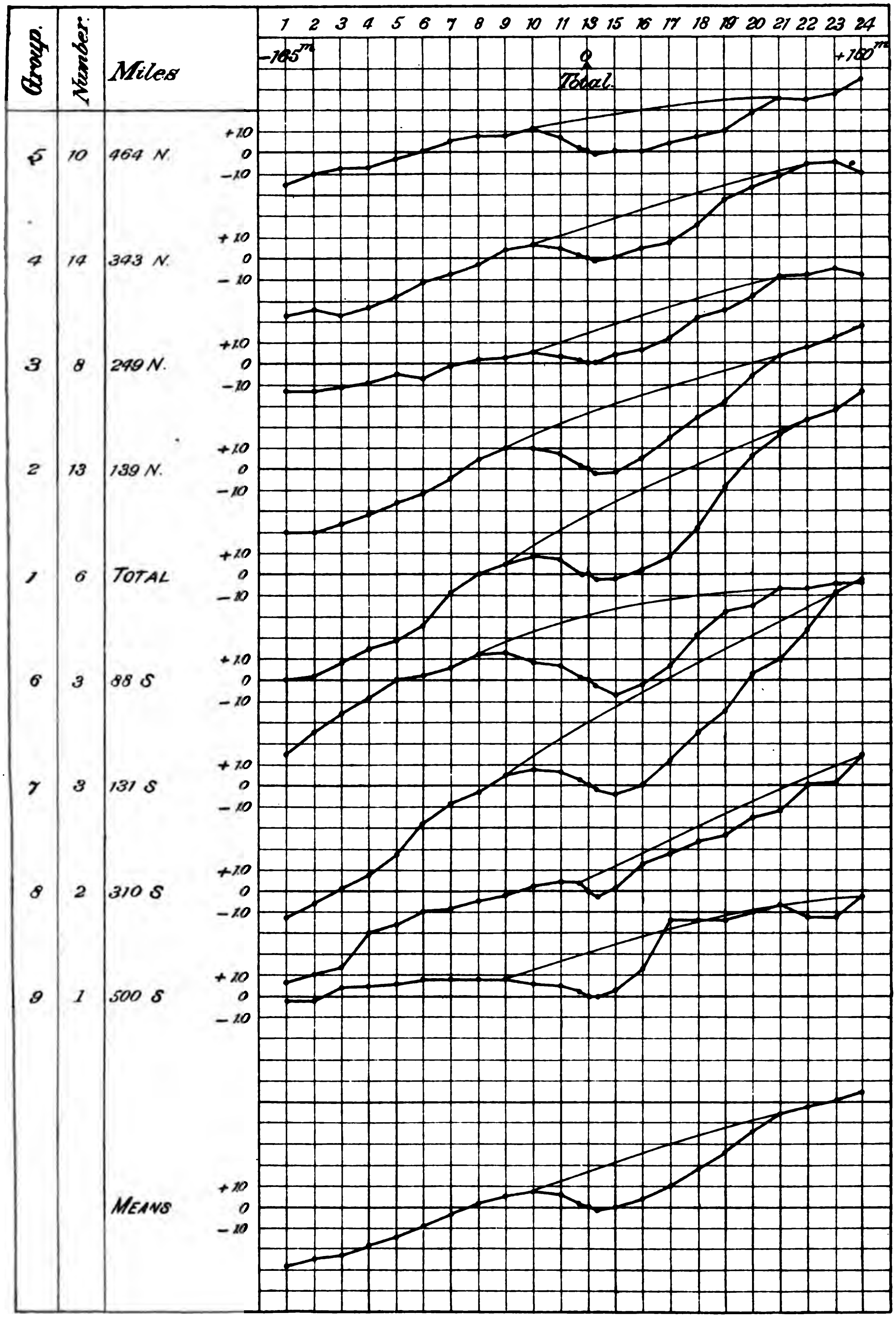


TABLE 6.—*Vapor pressure variations during the total eclipse of May 28, 1900.*

[Referred to the vapor pressure at the moment of totality.]

Station	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
1. New Orleans	0	.000	.000	.000	−.026	−.026	−.026	.000	.000	−.050	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	−.026	−.026	−.026	−.050	−.076
Raleigh	6 N	−59	−59	−59	−59	−45	−45	−45	−30	−15	0	+16	+33	.000	+33	+16	+16	0	+16	+16	−15	−15	−30	−45	−30
Norfolk	15 N	−31	−31	−31	−16	0	0	+51	+32	+51	+33	+33	−16	.000	+17	+17	+33	+51	+88	+51	+69	+33	+17	+69	+51
Mobile	35 S	0	0	0	0	0	0	0	0	0	0	0	0	.000	0	−16	0	0	0	0	0	0	0	0	0
Charlotte	25 N	−15	−15	−15	−15	0	−29	0	0	−15	−15	0	−15	.000	−15	−15	0	+15	−15	−15	0	0	−29	+15	+15
Montgomery	27 N	−40	−40	−40	−40	−40	−40	−40	−20	−20	−20	0	0	.000	0	0	+43	+21	+43	+43	+43	+43	+43	0	+21
Means	**16**	**−24**	**−24**	**−24**	**−26**	**−19**	**−23**	**−6**	**−3**	**−8**	**0**	**+8**	**0**	**.000**	**+6**	**0**	**+15**	**+15**	**+22**	**+16**	**+12**	**+6**	**−4**	**−2**	**−3**
2. Atlanta	40 N	−72	−72	−72	−72	−59	−45	−30	−45	−30	−30	−15	0	.000	0	0	0	0	0	+16	0	0	+32	+16	+32
Meridian	95 N	−68	−89	−68	−89	−68	−46	−46	−24	−24	−24	0	0	.000	0	0	0	+23	0	0	−68	−24	−46	−46	−98
Lynchburg	110 N	−64	−64	−49	−64	−32	−64	−79	−26	−6	−26	+57	−16	.000	−16	0	−16	−33	−16	+18	−33	−33	−33	−16	−33
Galveston	125 N	0	0	0	−25	0	0	0	+25	0	0	+25	0	.000	0	0	+25	+25	+25	+51	+51	+25	+78	+25	+51
Atlantic City	135 N	+15	+15	+15	0	0	0	0	0	0	0	0	0	.000	0	0	0	0	0	0	0	+15	+15	+15	+15
Corpus Christi	140 N	+25	+25	−25	+25	0	−25	0	−25	0	0	0	+25	.000	0	−25	0	0	+25	+25	0	+25	+51	+25	+25
Chattanooga	140 N	+15	+15	+15	+31	+31	−15	0	0	0	0	−15	−15	.000	0	0	+15	+48	+48	+64	+31	−57	−57	−15	0
Vicksburg	155 N	−46	−46	−46	−46	−46	−46	−24	−24	0	0	0	0	.000	0	0	0	+23	0	0	0	0	0	−24	−24
Knoxville	160 N	−16	−16	−16	0	+18	0	−16	0	−16	−33	0	0	.000	−16	0	0	0	0	−16	+36	+18	−49	−16	−64
Washington	160 N	−27	−27	−40	−27	−27	−27	−14	−27	−14	−27	−14	−14	.000	−14	0	0	−14	−14	0	+15	+15	+15	+30	+15
Baltimore	180 N	−51	−51	−51	−39	+14	−51	−51	−51	−13	−26	−26	−13	.000	0	0	−13	−13	0	0	+14	+44	+61	+75	+75
Nantucket	180 N	0	+12	+12	+12	+12	+12	+24	+12	+24	0	0	0	.000	−23	−23	−23	−23	−23	−33	−23	−44	−44	−23	−23
Philadelphia	190 N	−49	−33	−49	−33	−33	−33	−33	−49	−49	−16	−16	−16	.000	−16	−16	−16	0	−16	−16	−16	−16	−16	−16	−16
Means	**139**	**−26**	**−25**	**−25**	**−25**	**−15**	**−26**	**−21**	**−18**	**−10**	**−14**	**−0**	**−4**	**.000**	**−7**	**−5**	**−2**	**+3**	**+2**	**+8**	**+1**	**−2**	**+1**	**+2**	**−3**
3. Block Island	210 N	+24	0	0	−12	0	−12	−12	−12	−12	0	−12	0	.000	0	0	0	0	0	0	−12	−12	−12	−23	−23
New York	220 N	−15	−27	−14	−27	−14	−27	−14	−14	0	0	0	0	.000	0	+15	+15	0	0	0	0	0	+15	+15	−27
New Haven	240 N	+89	+62	+75	+62	+75	+62	+75	+62	+62	+89	+36	+12	.000	0	+12	0	0	−22	−22	−12	−32	−21	−21	0
Harrisburg	260 N	−42	0	−15	−68	−42	−29	+15	−15	+15	+15	−15	−29	.000	0	−29	0	−42	−42	−29	−42	−15	−29	−15	−42
San Antonio	260 N	0	0	−24	−24	−24	−46	0	0	−24	0	0	0	.000	0	0	0	−46	0	−24	−46	−24	−24	−46	−68
Nashville	260 N	−71	−55	−55	−55	−71	−71	−37	−55	−19	−19	−19	0	.000	0	−19	−37	0	−55	−55	−55	−19	−55	−19	−37
Shreveport	260 N	0	0	0	0	0	0	0	0	0	0	0	0	.000	0	+24	0	0	0	0	+24	+24	−22	−22	0
Boston	280 N	+20	+10	+10	+10	+10	+20	+10	+10	0	0	+10	0	.000	0	0	0	−9	0	−9	−9	−9	−18	−18	−9
Means	**249**	**+1**	**−1**	**−3**	**−14**	**−8**	**−13**	**+5**	**−3**	**+3**	**+11**	**0**	**−2**	**.000**	**0**	**0**	**−3**	**−12**	**−15**	**−17**	**−19**	**−11**	**−21**	**−19**	**−26**
4. Palestine	300 N	−22	−43	−43	−83	−22	−22	−43	−43	0	0	+22	+22	.000	0	0	0	0	0	+22	+22	0	+22	+22	0
Parkersburg	300 N	−17	0	0	+18	+18	+18	0	−18	0	0	0	0	.000	0	0	0	−18	0	0	−18	+56	+96	+39	+17
Lexington	300 N	−71	−71	−71	−55	−55	−71	−71	−47	−19	−37	0	−18	.000	−18	−18	−37	−19	−19	0	−37	−37	+19	0	0
Memphis	300 N	0	0	+22	+22	+22	+22	+22	−21	+22	+22	+22	+22	.000	+22	+22	+22	+22	+22	+44	+22	+22	+22	0	−21
Pittsburg	335 N	+17	0	+17	0	0	+17	0	+17	0	0	−16	+51	.000	0	0	+17	0	+33	+17	+33	0	+69	0	+17
Little Rock	340 N	−63	−43	−43	−63	−43	−63	−43	−43	−43	−43	0	0	.000	−22	−22	+46	0	0	0	−43	−43	+46	+46	+22
Albany	345 N	+21	+21	+21	+21	+10	+21	+33	+33	0	+10	−11	−11	.000	−11	−11	0	+45	+10	0	+21	+21	−11	+10	+21
Louisville	350 N	−38	−38	−56	−38	−56	−56	−38	−19	−38	0	0	0	.000	0	0	0	−19	+20	+20	0	0	0	0	+20

TABLE 6.—*Vapor pressure variations during the total eclipse of May 28, 1900*—Continued.

Station	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
4. Binghamton	350 N	− 30	− 45	− 15	− 45	0	+ 16	+ 16	+ 16	+ 16	0	0	0	.000	0	+ 33	0	+ 16	+ 16	+ 16	+ 16	+ 33	+ 33	+ 16	− 15
Portland	360 N	+ 31	+ 31	+ 49	+ 31	+ 31	+ 15	+ 15	+ 7	+ 31	+ 7	0	0	.000	0	0	+ 15	+ 15	+ 15	+ 15	+ 31	+ 39	+ 23	+ 31	+ 7
Cincinnati	370 N	0	− 19	− 38	− 19	− 19	0	0	− 19	− 19	0	− 19	0	.000	− 19	− 19	− 19	0	− 19	− 19	− 19	− 19	0	0	0
Cairo	380 N	+ 22	+ 22	0	0	0	0	− 22	− 22	− 22	− 22	0	0	.000	0	− 22	− 22	0	0	+ 22	+ 46	+ 46	+ 22	+ 22	+ 46
Columbus	380 N	0	0	0	0	0	+ 18	+ 18	+ 18	+ 18	+ 18	+ 18	0	.000	+ 18	0	0	0	0	0	+ 18	0	0	0	+ 18
Eastport	390 N	− 43	− 35	− 27	0	0	− 9	0	0	0	0	0	0	.000	0	0	0	0	+ 10	+ 20	− 20	+ 10	+ 20	+ 20	+ 20
Means	**348**	**− 14**	**− 15**	**− 18**	**− 15**	**− 8**	**− 7**	**− 8**	**− 10**	**− 4**	**− 3**	**+ 1**	**+ 5**	**.000**	**− 2**	**− 3**	**+ 3**	**+ 3**	**+ 6**	**+ 11**	**+ 5**	**+ 9**	**+ 26**	**+ 15**	**+ 11**
5. Northfield	425 N	− 47	− 47	− 47	− 36	− 47	− 36	− 47	− 24	− 24	− 24	0	0	.000	− 12	0	0	− 12	0	− 36	− 24	− 24	− 36	− 36	− 24
Cleveland	445 N	+ 17	+ 17	+ 17	+ 17	+ 33	+ 33	+ 17	+ 33	+ 17	0	+ 17	0	.000	0	+ 17	+ 33	+ 33	+ 33	+ 33	+ 17	+ 17	+ 33	+ 33	+ 33
Erie	450 N	− 33	− 33	− 33	− 17	− 17	− 17	− 17	0	0	0	0	0	.000	0	0	0	0	0	0	− 17	0	0	0	+ 34
Oswego	450 N	+ 15	+ 31	+ 31	+ 31	+ 31	+ 31	+ 31	+ 49	+ 49	+ 31	+ 31	+ 31	.000	0	+ 15	+ 31	+ 15	+ 15	+ 31	+ 15	+ 15	0	0	− 15
Indianapolis	450 N	+ 39	+ 39	+ 39	+ 19	0	+ 19	0	0	0	+ 19	+ 19	+ 19	.000	+ 19	+ 19	+ 19	+ 19	+ 19	+ 38	+ 19	0	+ 19	+ 19	+ 38
Rochester	460 N	0	+ 16	+ 49	+ 49	+ 49	+ 49	+ 49	+ 16	+ 16	0	+ 16	0	.000	+ 16	0	− 15	− 15	− 15	0	+ 16	+ 16	+ 33	+ 33	+ 16
Sandusky	465 N	− 18	− 18	− 18	− 18	− 18	− 18	0	0	0	0	0	0	.000	0	+ 18	0	0	0	0	+ 18	+ 18	+ 18	+ 18	+ 18
Buffalo	465 N	− 16	0	− 16	0	− 16	− 31	− 31	− 16	− 16	− 16	0	0	.000	+ 17	+ 17	+ 17	+ 33	0	0	+ 17	0	+ 17	+ 17	+ 17
Abilene	470 N	− 19	0	0	0	0	0	0	0	+ 20	0	0	0	.000	0	0	0	+ 20	+ 40	+ 20	+ 20	+ 20	+ 20	+ 40	+ 40
St. Louis	500 N	+ 85	+ 41	+ 20	0	− 20	+ 20	− 20	0	+ 20	0	0	0	.000	0	0	0	− 20	0	0	0	0	0	0	− 20
Springfield, Mo.	520 N	− 40	− 40	− 20	− 20	− 20	− 40	− 20	− 20	− 40	− 20	0	+ 19	.000	0	0	0	+ 21	+ 21	0	+ 21	+ 21	+ 21	0	0
Means	**464**	**− 2**	**+ 1**	**+ 2**	**+ 2**	**− 2**	**+ 1**	**+ 3**	**+ 3**	**+ 4**	**− 1**	**+ 8**	**+ 6**	**.000**	**+ 4**	**+ 8**	**+ 8**	**+ 9**	**+ 10**	**+ 8**	**+ 9**	**+ 8**	**+ 11**	**+ 11**	**+ 12**
6. Pensacola	65 S	0	0	0	+ 25	+ 25	+ 25	0	+ 25	0	+ 25	0	0	.000	− 25	− 25	− 48	− 48	− 48	− 48	− 48	− 48	− 48	− 48	− 48
Kitty Hawk	100 S	0	+ 33	+ 51	+ 69	+ 69	+107	+ 69	+ 88	+ 88	+ 88	+ 88	0	.000	+ 33	+ 69	+ 69	+ 69	+ 69	+ 51	+ 51	+ 51	+ 51	+ 51	+ 51
Hatteras	100 S	− 16	0	0	− 16	− 31	− 31	0	− 16	0	+ 33	+ 17	0	.000	0	+ 17	+ 17	0	0	0	0	+ 32	0	− 31	− 46
Means	**88**	**− 5**	**+ 11**	**+ 17**	**+ 26**	**+ 21**	**+ 34**	**+ 23**	**+ 32**	**+ 29**	**+ 49**	**+ 35**	**0**	**.000**	**+ 3**	**+ 20**	**+ 13**	**+ 7**	**+ 7**	**+ 1**	**+ 1**	**+ 12**	**+ 1**	**− 9**	**− 14**
7. Wilmington	110 S	− 30	− 44	− 30	− 44	− 57	− 57	− 30	− 44	− 44	− 57	− 57	− 30	.000	0	+ 15	0	− 15	0	+ 15	+ 15	− 30	0	− 15	0
Charleston	125 S	− 15	− 15	0	− 15	− 15	− 15	− 15	− 30	0	− 15	0	− 15	.000	0	0	0	+ 16	− 15	− 15	− 15	− 15	0	− 15	− 15
Savannah	158 S	+ 33	0	0	0	0	0	+ 18	+ 18	+ 36	+ 55	0	+ 18	.000	+ 18	+ 18	+ 55	+ 36	+ 18	− 16	0	− 49	− 64	− 64	− 64
Means	**131**	**− 4**	**− 20**	**− 10**	**− 20**	**− 24**	**− 24**	**− 9**	**− 19**	**− 3**	**− 6**	**− 19**	**− 9**	**.000**	**+ 6**	**+ 11**	**+ 18**	**+ 12**	**+ 1**	**− 5**	**0**	**− 31**	**− 21**	**− 31**	**− 26**
8. Jacksonville	240 S	+ 59	+ 39	+ 59	+ 39	+ 39	+ 39	+ 19	+ 19	+ 19	0	+ 19	0	.000	0	0	0	0	+ 19	− 37	− 37	− 55	− 55	− 55	− 19
Tampa	380 S	− 44	− 44	− 44	− 44	− 22	− 22	− 22	− 22	− 22	− 22	0	0	.000	− 22	0	− 22	0	0	0	− 22	− 22	+ 24	− 44	− 44
Means	**310**	**+ 8**	**− 3**	**+ 8**	**− 3**	**+ 9**	**+ 9**	**− 2**	**− 2**	**− 2**	**− 11**	**+ 10**	**0**	**.000**	**− 11**	**0**	**− 11**	**0**	**+ 10**	**− 19**	**− 30**	**− 39**	**− 16**	**− 50**	**− 32**
9. Jupiter	500 S	0	0	0	0	0	0	+ 25	+ 25	+ 25	+ 25	+ 25	+ 25	.000	0	0	+ 25	+ 50	+ 50	+ 50	+ 25	+ 76	+ 76	+ 25	+ 50
Means	....	− 12	− 12	− 10	− 13	− 8	− 10	− 5	− 5	− 1	0	+ 4	+ 1	.000	− 1	+ 1	+ 4	+ 5	+ 9	+ 5	+ 1	+ 1	+ 5	0	− 2
Shadow variations	....	....	....	....	....	....	....	....	....	....	.000	−.002	−.004	−.005	−.006	−.007	−.007	−.006	−.003	.000	....	....	....	....	....

CHART 9.

Vapor pressure variations.

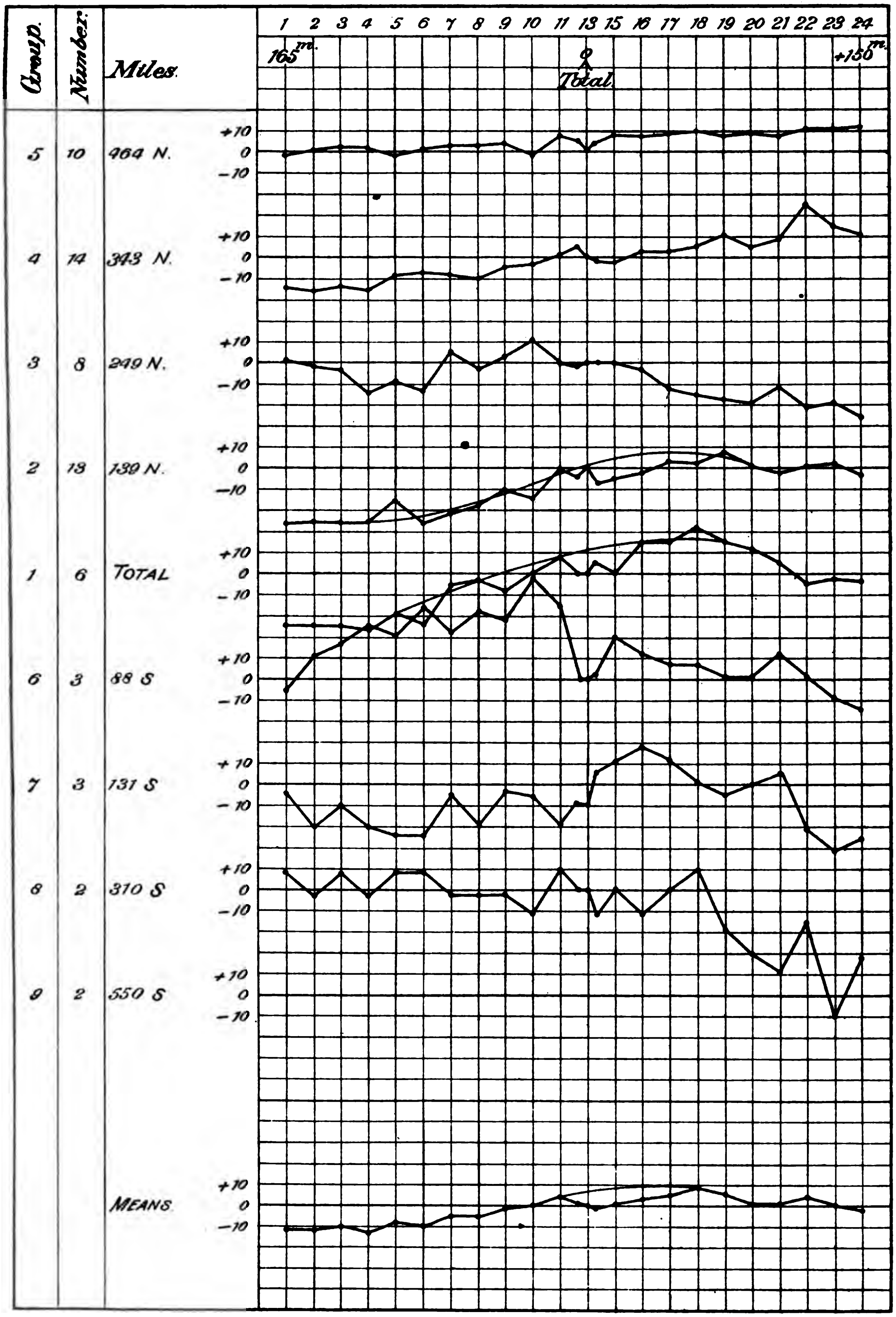


TABLE 7.—*Wind velocities during the total eclipse of May 28, 1900.*

Station	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
1. New Orleans	0	2	2	2	2	4	4	4	2	2	3	3	3	3	3	4	4	3	7	8	5	8	6	7	7
Raleigh	6 N	3	1	0	1	1	3	4	3	3	6	4	3	4	3	4	5	6	6	6	7	7	8	7	5
Norfolk	15 N	3	3	3	2	3	3	2	2	2	3	3	5	5	4	4	4	6	6	6	8	8	10	10	11
Mobile	25 S	2	3	4	4	4	5	5	3	3	4	4	4	3	3	3	3	5	3	4	4	5	5	6	6
Charlotte	25 N	7	7	7	6	4	4	4	6	8	7	8	8	8	7	6	6	7	8	9	9	10	9	9	8
Montgomery	27 N	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	3	4
Mean *v*	16 N	3.0	2.7	2.8	2.7	2.8	3.3	3.3	2.8	3.2	4.0	3.8	4.0	4.0	3.5	3.7	3.8	4.7	5.2	5.7	5.8	6.7	6.5	7.0	6.8
2. Atlanta	40 N	11	11	12	12	10	9	10	9	9	10	11	8	8	8	8	6	6	9	8	8	8	7	10·	8
Meridian	95 N	1	1	1	1	1	1	1	1	1	1	2	3	3	3	3	3	2	2	2	3	3	3	6	6
Lynchburg	110 N	3	1	1	1	1	1	1	1	1	2	2	2	2	3	1	1	1	1	3	2	2	2	2	2
Galveston	125 N	2	2	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	6	5	8
Atlantic City	135 N	4	4	4	5	6	8	6	6	6	9	7	7	6	6	6	7	6	5	5	5	8	6	8	7
Corpus Christi	140 N	7	6	6	5	5	5	4	3	3	4	4	4	4	4	4	3	2	3	3	4	5	6	6	6
Chattanooga	140 N	2	1	1	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	3	7	5
Vicksburg	155 N	6	6	6	7	6	6	6	7	6	7	5	5	5	5	4	3	3	3	3	4	5	5	6	5
Knoxville	160 N	4	5	5	4	3	2	3	3	3	4	5	6	6	6	5	4	4	7	10	6	7	10	11	12
Washington	160 N	3	3	3	3	3	3	3	3	4	4	4	4	4	4	3	3	3	4	6	6	5	5	5	5
Baltimore	180 N	0	2	3	4	4	4	3	3	4	4	4	3	3	3	3	3	3	3	3	3	2	3	3	3
Nantucket	180 N	19	18	16	18	15	20	19	20	17	20	20	18	19	18	20	20	20	17	16	16	20	21	24	21
Philadelphia	190 N	1	1	1	1	1	1	1	1	2	3	5	7	6	7	9	10	10	9	10	12	13	12	13	13
Mean *v*	139 N	4.9	4.6	4.7	5.0	4.5	5.1	4.9	4.9	4.8	4.9	5.6	5.3	5.2	5.3	5.2	4.9	4.6	5.0	5.4	5.4	6.1	7.1	7.8	7.6
3. Block Island	210 N	23	31	30	29	24	24	22	23	22	22	24	23	23	24	24	25	27	25	27	29	27	28	29	27
New York	220 N	20	28	25	26	26	24	26	27	24	25	27	29	27	23	26	16	23	20	22	14	11	11	15	12
New Haven	240 N	10	10	9	12	11	11	18	12	12	14	15	14	14	10	12	12	12	12	12	12	12	12	12	11
Harrisburg	260 N	2	2	2	2	2	2	2	1	1	4	4	4	4	4	2	4	3	3	3	5	5	6	9	12
San Antonio	260 N	2	2	2	2	2	2	2	2	2	2	2	1	0	0	1	1	2	2	4	5	6	7	7	5
Nashville	260 N	2	2	2	2	2	2	2	2	2	3	3	3	3	3	2	2	2	5	6	5	5	8	8	6
Shreveport	260 N	5	5	5	4	4	4	5	9	7	4	4	4	4	3	3	2	5	5	6	6	5	5	9	7
Boston	280 N	13	12	13	15	15	18	15	16	15	16	13	12	10	11	12	12	13	13	15	12	18	11	15	14
Mean *v*	249 N	9.6	11.5	11.0	11.5	10.8	10.9	11.5	11.5	10.6	11.3	11.4	11.3	10.6	9.8	10.3	9.3	10.9	10.6	11.9	11.0	11.1	11.0	13.0	11.8
4. Palestine	300 N	5	5	5	5	4	4	4	6	7	7	7	7	5	4	5	4	4	5	7	6	7	10	8	9
Parkersburg	300 N	0	0	0	0	0	0	0	2	3	3	3	2	2	2	2	2	5	8	7	4	2	2	2	2
Lexington	300 N	7	7	7	7	7	7	7	9	9	9	8	7	7	7	7	7	8	11	11	10	12	14	14	14
Memphis	300 N	7	6	6	7	8	8	10	9	9	10	9	8	10	10	11	15	12	14	10	11	12	14	12	8
Pittsburg	335 N	1	1	1	1	2	2	2	3	4	4	3	5	5	4	4	2	3	4	5	4	4	8	4	5
Little Rock	340 N	4	3	2	2	2	4	0	4	2	2	4	3	3	5	6	6	3	6	6	9	10	10	6	9
Albany	345 N	6	8	6	8	8	8	9	8	5	9	8	8	9	8	8	8	9	8	10	8	6	8	8	8
Louisville	350 N	6	5	5	6	8	5	5	6	7	6	5	4	4	4	4	4	4	6	5	7	8	8	10	9
Binghamton	350 N	3	4	4	2	6	4	4	4	4	2	4	6	6	3	3	3	4	3	5	8	7	7	4	8

TABLE 7.— *Wind velocities during the total eclipse of May 28, 1900*—Continued.

Station	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
4. Portland	360 N	12	10	9	9	10	11	13	11	10	10	9	11	10	11	8	8	8	8	8	8	9	8	10	12
Cincinnati	370 N	2	2	2	4	4	5	4	3	3	3	6	11	8	8	7	7	8	6	5	8	8	7	8	5
Cairo	380 N	4	4	7	7	7	4	6	7	6	6	4	4	4	4	5	3	3	6	7	7	6	8	10	9
Columbus	380 N	7	7	5	5	2	2	2	6	5	3	5	5	5	5	5	5	6	5	4	7	7	7	7	6
Eastport	390 N	7	10	7	9	11	11	8	8	9	7	6	5	3	3	3	6	4	4	7	12	12	11	7	6
Mean *v*	343 N	5.1	5.1	4.7	5.1	5.6	4.7	5.3	6.1	5.9	5.8	5.8	6.1	5.8	5.6	5.6	5.7	5.8	6.7	6.9	7.8	7.9	8.7	7.9	7.9
5. Northfield	425 N	14	13	20	20	20	13	13	12	11	12	9	8	5	5	6	5	5	8	9	9	11	11	8	12
Cleveland	445 N	8	7	10	7	8	6	6	3	5	4	4	5	5	6	8	13	17	19	20	14	13	12	10	9
Erie	450 N	6	6	6	7	7	8	7	6	6	6	5	6	6	6	6	6	4	5	5	6	4	4	1	2
Oswego	450 N	3	3	3	4	4	4	3	4	4	3	3	5	5	7	5	5	8	6	8	9	8	9	10	9
Indianapolis	450 N	11	6	4	7	12	9	6	9	8	13	13	15	14	14	15	9	7	10	6	5	7	5	6	5
Rochester	460 N	3	3	3	3	3	3	4	3	5	4	5	5	5	5	5	5	6	6	6	9	8	9	8	8
Sandusky	465 N	8	4	4	4	5	4	4	5	4	4	5	4	4	5	5	8	8	7	7	5	4	4	2	2
Buffalo	465 N	4	6	8	9	8	8	7	6	5	6	5	5	6	7	8	6	2	3	3	3	4	4	3	4
Abilene	470 N	5	6	12	11	12	12	12	14	12	12	9	10	9	12	12	15	16	12	10	10	14	12	11	11
St. Louis	500 N	4	4	6	6	12	13	6	7	9	8	6	5	5	6	8	8	7	9	10	10	11	7	8	6
Springfield	520 N	4	6	7	6	6	6	8	8	6	6	7	6	6	8	6	8	8	7	8	7	12	7	8	7
Mean *v*	464 N	6.4	5.8	7.5	7.6	8.8	7.8	6.9	7.0	6.8	7.1	6.5	6.7	6.4	7.4	7.6	8.0	8.0	8.4	8.4	7.9	8.7	7.6	6.8	6.8
6. Pensacola	65 S	6	5	8	5	7	5	10	7	10	9	12	10	12	14	12	10	8	12	12	15	10	12	11	14
Kitty Hawk	100 S	0	0	0	0	1	0	6	5	4	3	0	0	1	0	0	4	4	4	4	4	4	4	4	4
Hatteras	100 S	2	2	2	3	2	2	2	2	2	2	2	2	2	2	1	4	4	2	2	2	2	4	6	6
Mean *v*	88 S	2.7	2.3	3.3	2.7	3.3	2.3	6.0	4.7	5.3	4.7	4.7	4.0	5.0	5.3	4.3	6.0	5.3	6.0	6.0	7.0	5.3	6.7	7.0	8.0
7. Wilmington	110 S	5	4	5	6	7	9	9	9	9	8	9	6	6	6	5	4	4	6	4	4	5	10	3	6
Charleston	125 S	6	7	6	8	9	9	8	11	9	8	9	8	7	7	8	8	10	8	8	10	12	14	9	9
Savannah	158 S	3	2	3	4	7	6	7	5	6	6	5	5	5	4	4	3	4	6	7	5	5	4	8	4
Mean *v*	131 S	4.7	4.3	4.7	6.0	7.7	8.0	8.0	8.3	8.0	7.3	7.7	6.3	6.0	5.7	5.7	5.0	6.0	6.7	6.3	6.3	7.3	9.3	6.7	6.3
8. Jacksonville	240 S	5	4	3	3	3	4	5	6	8	9	8	8	6	6	6	6	8	10	9	8	7	6	8	8
Tampa	380 S	5	4	5	5	5	5	5	6	5	6	5	5	5	5	4	3	5	7	10	10	8	7	8	6
Mean *v*	310 S	5.0	4.0	4.0	4.0	4.0	4.5	5.0	6.0	6.7	7.5	6.5	6.5	5.5	5.5	5.0	4.5	6.5	8.5	9.5	9.0	7.5	6.5	8.0	7.0
9. Jupiter	500 S	12	9	10	11	11	9	10	9	10	9	10	10	9	10	10	10	10	12	12	11	11	10	12	10
Key West	600 S	3	5	7	7	8	9	12	12	12	14	8	8	7	6	5	7	6	6	10	10	12	12	11	12
Mean *v*	550 S	7.5	7.0	8.5	9.0	9.5	9.0	11.0	10.5	11.0	11.5	9.0	9.0	8.0	8.0	7.5	8.5	8.0	9.0	11.0	10.5	11.5	11.0	11.5	11.0
Means		5.6	5.6	5.9	6.1	6.4	6.3	6.4	6.6	6.4	6.6	6.6	6.5	6.3	6.3	6.3	6.3	6.6	7.1	7.5	7.5	7.9	8.2	8.3	8.0

CHART 10.

Wind velocity variations.

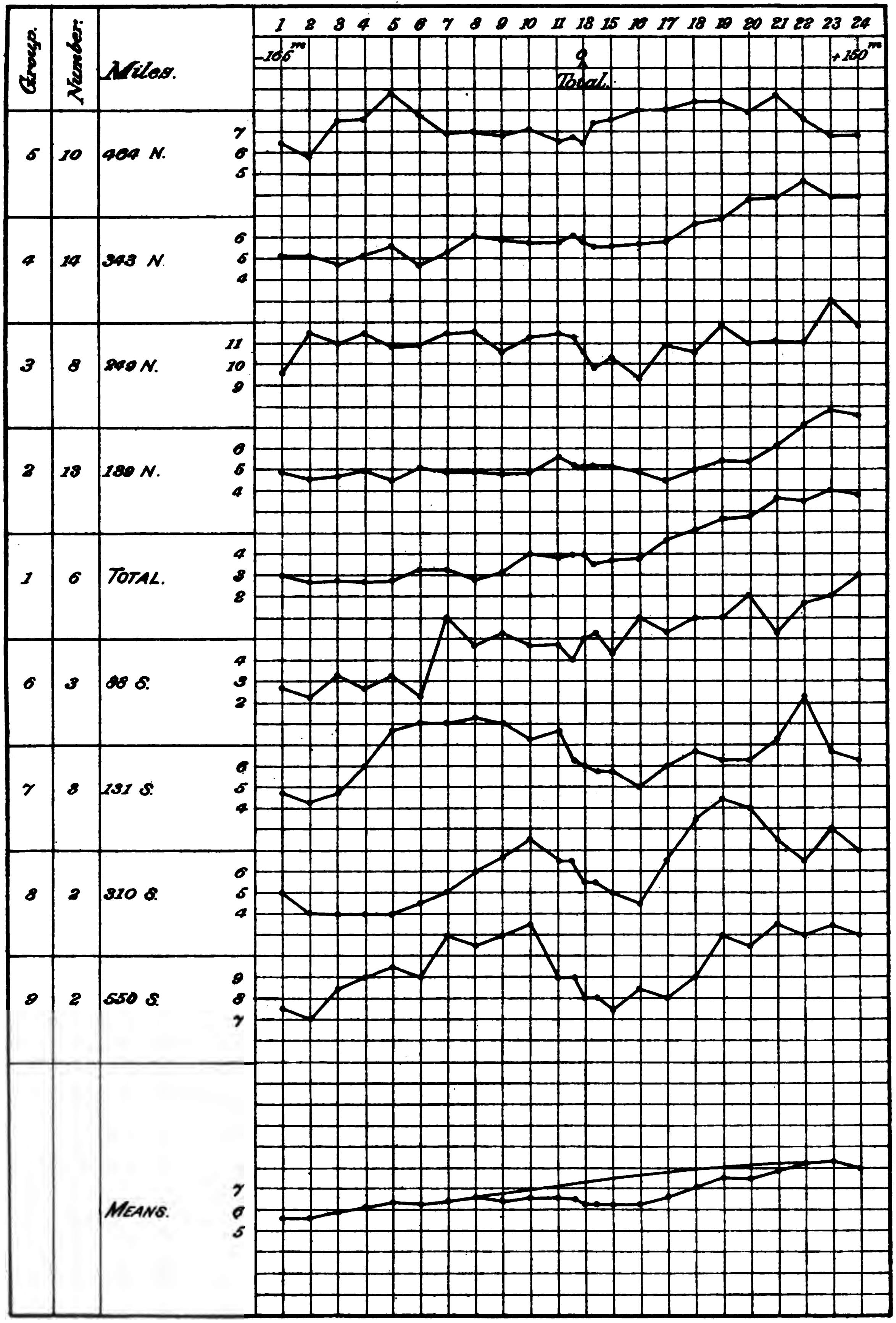


TABLE 8.—*Wind azimuths during the total eclipse of May 28, 1900.*

	Dist. Cent.	1 −165	2 150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total.	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
1. New Orleans	0	180	225	225	225	225	270	225	270	225	225	270	315	225	270	315	270	315	270	270	270	225	225	225	225
Raleigh	6 N	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	90	90	90	135
Norfolk	15 N	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
Mobile	25 S	315	315	315	315	315	315	315	270	270	270	315	315	315	315	315	315	315	315	315	315	315	315	315	315
Charlotte	25 N	180	180	180	180	180	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
Montgomery	27 N	225	......	225	225	225	225	225	270	270	270	270	270	270	270	270	270	270	270	270	315	315	315	315	315
Mean φ	16 N	203	207	210	210	210	210	203	210	203	203	217	226	210	217	226	217	226	217	217	226	210	210	210	218
2. Atlanta	40 N	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	90	90	135
Meridian	95 N	180	180	180	180	180	180	180	180	180	180	190	180	180	180	180	135	135	135	135	180	135	135	135	135
Lynchburg	110 N	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
Galveston	125 N	180	180	......	......	......	......	......	315	......	......	......	......	......	......	......	......	270	270	315	270	315	220	270	270
Atlantic City	135 N	135	135	135	135	135	180	180	180	180	135	180	135	180	180	180	180	180	180	180	135	135	135	135	135
Corpus Christi	140 N	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	225	225	225	225	270	270
Chattanooga	140 N	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	225	225	225
Vicksburg	155 N	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	180	......	......	180	......	180	......
Knoxville	160 N	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	135	135	135	180	180	180	180
Washington	160 N	180	180	180	180	180	180	180	180	225	225	180	180	180	180	180	225	225	225	180	180	225	225	225	225
Baltimore	180 N	......	225	180	180	180	180	180	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	225
Nantucket	180 N	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
Philadelphia	190 N	90	90	90	90	90	90	90	90	180	180	270	270	270	270	270	315	270	270	315	315	315	270	270	315
Mean φ	....	176	180	176	176	176	180	180	187	188	184	191	188	191	191	191	195	297	187	199	195	201	195	197	214
3. Block Island	210 N	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	270
New York	220 N	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	270	315	315	315	315
New Haven	240 N	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
Harrisburg	260 N	180	180	180	180	180	180	180	180	180	90	90	90	90	90	90	90	90	90	90	315	270	315	315	270
San Antonio	260 N	225	315	315	315	315	315	315	315	315	315	315	315	......	......	315	315	225	225	180	180	180	180	180	180
Nashville	260 N	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	180	135	135	135	135	135	135
Shreveport	260 N	225	225	225	225	225	225	225	225	225	180	180	135	135	135	135	180	180	180	180	180	180	225	225	225
Boston	280 N	315	315	315	315	315	315	315	315	315	315	315	315	360	315	360	315	360	315	315	315	315	315	315	315
Mean φ	249	270	281	281	281	281	281	281	281	281	264	264	259	257	251	264	264	259	242	231	253	253	264	264	253
4. Palestine	300 N	180	180	180	180	180	180	225	225	225	......	180	180	......	180	180	180	180	180	180	135	135	135	135	135
Parkersburg	300 N	......	......	......	......	......	......	......	180	180	225	315	225	225	225	225	225	225	225	225	135	135	180	180	221
Lexington	300 N	225	225	225	180	225	180	180	180	180	180	180	180	180	180	180	180	180	225	225	225	180	225	135	135
Memphis	300 N	180	180	180	180	180	180	135	135	135	135	135	135	135	135	135	180	135	135	135	135	135	135	135	135
Pittsburg	335 N	45	45	45	45	45	45	45	45	90	90	90	45	45	90	90	90	90	135	135	90	90	135	90	180
Little Rock	340 N	135	90	90	90	90	90	......	225	135	135	180	180	180	180	180	225	225	225	225	225	225	225	180	225
Albany	345 N	225	180	180	180	180	180	180	180	180	225	180	180	180	180	180	180	180	180	180	180	180	180	225	225
Louisville	350 N	180	180	180	180	180	180	180	225	180	180	225	225	180	180	180	180	180	180	180	180	180	135	135	135

TABLE 8.—*Wind azimuths during the total eclipse of May 28, 1900*—Continued.

	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total.	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
4. Binghamton	350 N	90	90	90	90	90	90	90	90	90	90	90	45	45	45	45	45	45	45	45	45	45	45	360	315
Portland	360 N	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	270	270
Cincinnati	370 N	180	180	180	135	225	225	225	225	225	225	45	360	360	360	360	360	360	315	315	315	315	270	315	315
Cairo	380 N	135	135	180	225	225	270	270	270	270	270	270	225	225	225	225	225	225	225	225	225	225	180	180	180
Columbus	380 N	225	225	225	315	315	225	180	180	135	135	135	135	135	135	135	135	135	135	135	135	135	90	90	90
Eastport	390 N	315	315	315	315	315	315	315	315	315	315	360	360	360	360	315	270	270	315	315	315	315	315	315	315
Mean φ	343	187	180	183	187	197	190	195	199	190	194	193	199	197	199	197	199	196	202	202	190	186	183	196	206
5. Northfield	425 N	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
Cleveland	445 N	180	180	135	135	90	90	135	90	360	315	315	315	315	315	225	225	225	225	225	225	225	225	180	90
Erie	450 N	180	180	180	180	180	180	180	180	180	180	180	180	135	135	135	135	135	135	135	135	135	135	135	135
Oswego	450 N	315	315	360	360	315	315	315	315	315	360	315	360	360	360	360	360	360	360	360	360	360	360	360	360
Indianapolis	450 N	360	360	360	360	135	135	135	135	135	135	180	180	180	180	180	180	180	360	270	315	315	315	315	315
Rochester	460 N	135	135	135	135	135	135	135	135	360	360	360	360	360	360	360	360	315	315	315	315	315	315	315	315
Sandusky	465 N	135	135	135	180	135	225	225	225	225	225	225	225	180	180	180	135	135	135	135	135	135	135	135	180
Buffalo	465 N	180	225	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	135	135	135	135
Abilene	470 N	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	225	180	135	135	135	225	135	180
St. Louis	500 N	180	180	180	135	135	135	180	180	180	180	180	180	180	135	135	135	135	180	135	135	135	90	90	90
Springfield	520 N	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	135	135	135
Mean φ	464	205	209	213	213	180	188	196	192	237	237	237	241	233	229	221	217	213	229	213	217	205	205	192	192
6. Pensacola	65 S	315	315	315	315	315	315	270	315	270	315	270	270	270	270	270	270	270	270	270	270	270	270	225	225
Kitty Hawk	100 S	......	......	......	......	135	......	270	180	270	270	225	180	180	180	180	225	225	225	225	225	225	225	225	225
Hatteras	100 S	90	90	90	135	135	135	135	135	135	135	135	135	135	135	135	225	225	225	225	225	270	225	225	270
Mean φ	88	202	203	202	225	195	225	225	210	225	240	210	195	195	195	195	240	240	240	240	240	255	240	225	240
7. Wilmington	110 S	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	45	45	45	90	90
Charleston	125 S	135	90	45	90	90	90	45	90	90	90	90	90	90	90	90	90	45	45	45	45	45	45	45	45
Savannah	158 S	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	135	180
Mean φ	131	105	90	75	90	90	90	75	90	90	90	90	90	90	90	90	90	75	75	75	60	60	60	90	105
8. Jacksonville	240 S	270	270	270	270	270	270	270	225	270	270	270	270	270	270	270	270	270	225	225	225	225	225	225	225
Tampa	380 S	315	315	315	315	315	315	315	315	315	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
Mean φ	310	293	293	292	292	292	292	292	270	292	270	270	270	270	270	270	270	270	248	248	248	248	248	248	248
9. Jupiter	500 S	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
Key West	600 S	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270	270
Mean φ	550	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292	292
Means	....	204	205	209	208	203	205	207	206	215	213	214	215	214	211	207	214	213	210	210	209	206	205	207	213

CHART 11.

Wind azimuth variations.

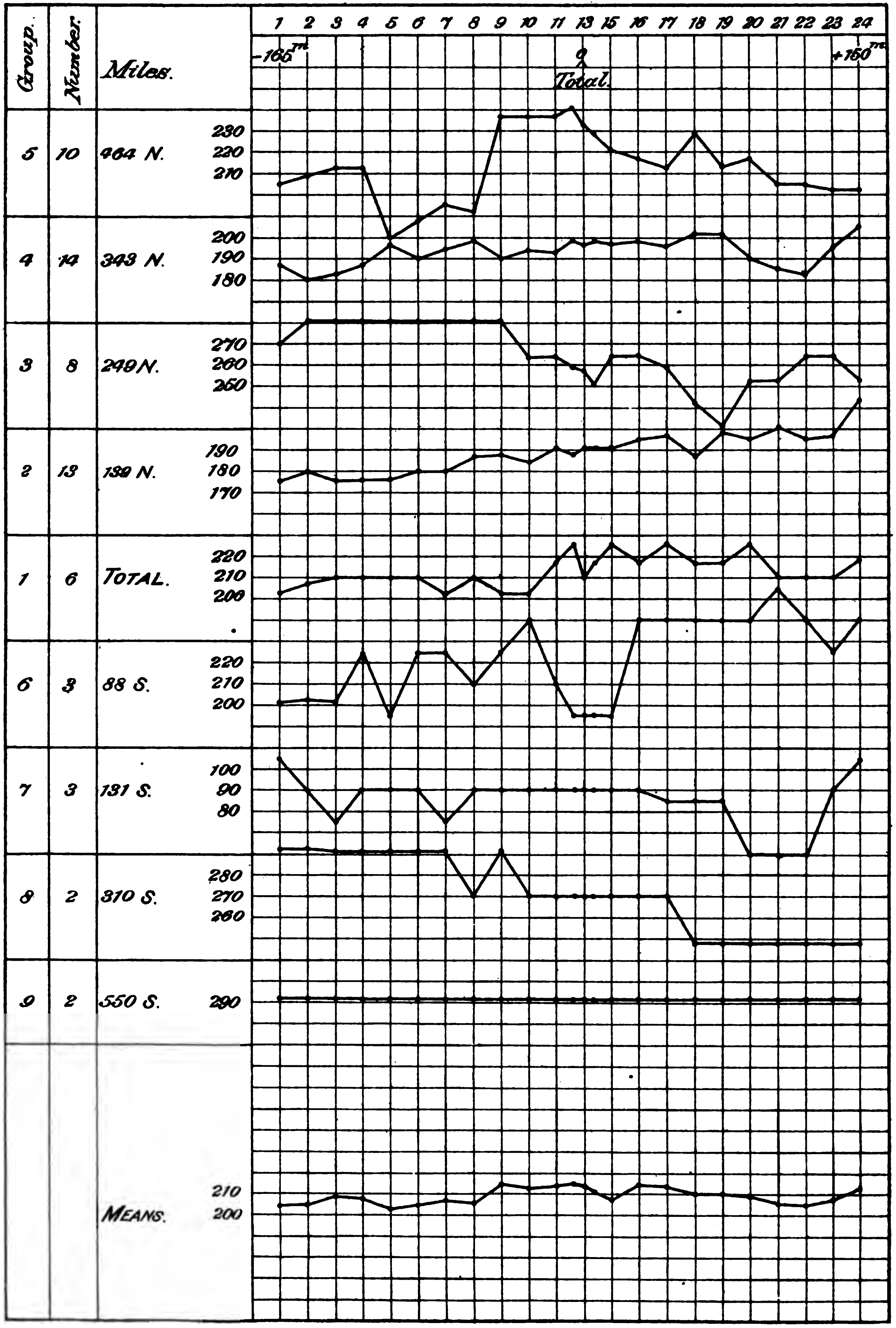


TABLE 9.—*Amount of cloudiness during the total eclipse of May 28, 1900.*

Stations	Dist. Cent.	1 −165	2 −150	3 −135	4 −120	5 −105	6 −90	7 −75	8 −60	9 −45	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105	22 +120	23 +135	24 +150
New Orleans	0	......	1	1	5	5	3	3	2	2	2	1	......	......	......	......	......	......	1	4	6	6	7	6	7
Raleigh	6 N	......	......	......	......	......	......	......	......	......	......	......	......	......	1	1	......	2	1	1	1	1	1	1	1
Norfolk	15 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Mobile	25 S	3	4	4	3	2	1	2	8	5	7	6	4	3	3	5	6	3	3	4	4	4	4	4	4
Charlotte	25 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Montgomery	27 N	3	2	......	......	......	1	1	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Atlanta	40 N	1	......	......	......	......	......	......	......	......	......	2	1	1	......	2	......	1	......	......	......	......	......	......	......
Pensacola	65 S	1	1	1	......	......	......	......	1	2	3	4	4	5	2	3	......	......	......	......	......	......	......	......	......
Meridian	95 N	6	6	6	8	9	9	7	8	6	5	4	3	2	2	1	1	1	1	3	3	2	2	2	2
Kitty Hawk	100 S	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Hatteras	100 S	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Lynchburg	110 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Wilmington	110 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Galveston	125 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Charleston	125 S	5	4	5	5	5	5	5	5	7	7	7	6	6	6	6	6	5	5	5	5	5	5	6	6
Atlantic City	135 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Corpus Christi	140 N	......	......	......	......	......	......	......	2	3	4	1	......	......	......	1	1	1	......	......	1	3	3	3	1
Chattanooga	140 N	1	1	......	......	......	......	1	2	......	......	......	......	1	1	......	2	......	......	......	......	......	......	......	......
Vicksburg	155 N	2	2	1	1	2	1	......	......	......	......	......	1	1	......	......	......	......	......	1	1	2	3	4	4
Savannah	158 S	5	7	5	8	8	8	9	9	8	8	8	8	8	8	8	7	7	7	6	5	5	5	5	6
Knoxville	160 N	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Washington	160 N	1	1	1	2	6	8	9	10	10	10	10	10	10	7	7	7	6	6	6	6	8	9	10	10
Baltimore	180 N	9	8	8	6	4	4	6	4	3	4	8	8	7	7	8	8	9	6	5	5	5	4	5	4
Nantucket	180 N	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Philadelphia	190 N	......	......	......	......	......	......	......	......	......	......	1	5	7	7	7	5	5	6	4	3	4	4	7	8
Block Island	210 N	10	10	10	10	9	10	9	9	10	10	10	10	10	10	10	10	10	10	10	10	9	8	7	8
Means	....	**2.2**	**2.2**	**2.0**	**2.2**	**2.3**	**2.3**	**2.4**	**2.7**	**2.7**	**2.7**	**2.8**	**2.7**	**2.7**	**2.5**	**2.6**	**2.4**	**2.3**	**2.2**	**2.3**	**2.3**	**2.5**	**2.5**	**2.7**	**2.7**

TEMPERATURE.

Precisely the same method was employed in discussing the temperature observations in Table 5 and on Chart 8 as for the pressure variations. In marked contrast with the uncertainty pertaining to the pressure, the variations of temperature are very clearly defined. The course of the usual diurnal range is interrupted at No. 9, 45 minutes before totality, so that the curve drops to a minimum at No. 15, or even a few minutes earlier, namely, 10 or 15 minutes after totality, and recovers its normal course at No. 22, which is 2 hours after the moment of totality. The greatest lowering of the temperature is about 3°.5 in the total shadow, and this falls away irregularly to the north and the south. The local rates of absorption might perhaps be studied at the several stations by plotting the residuals Δt, but I have not attempted to carry out this differential work, though it might have given us some information regarding the integral absorption of the upper layers of the atmosphere.

VAPOR PRESSURE.

The variations of the vapor pressure are given on Table 6 and Chart 9. There is very great irregularity among the groups when compared with one another, but the means show that we must admit a decrease of the vapor tension of about 0.01 inch at the time of the maximum cooling of the air. This does not agree with the difference of saturation which would correspond with a change of 3° in the dew-point taken between 50° and 60° on the average, for that would be 0.05 inch. However, for a relative humidity of 70 per cent this becomes 0.035 inch. In the rapid motion of the shadow there was apparently a lack of sufficient time for the vapor contents to completely readjust themselves to the new temperatures, but this is evidently a cause for the production of a multitude of minute adjustment currents, especially on the edges of the umbra, which would produce in that place a series of mixing and turbulent minor movements of the air. Indeed, there should be set in motion a rapid interchange of small currents between the total shadow and the adjacent atmosphere, where the temperature and the vapor tension seek a new equilibrium, and this turbulent action along the edge of the umbral cone throughout the depth of the atmosphere is well calculated to produce what is known as "optical obscuration" or darkening due to such currents. The rays of light from the sun struggling through these congested minor currents would undergo all sorts of anomalous refractions and reflections, and could reach the observer only in the form of fluttering waves, partly dark and partly light, such as are observed in the well-known eclipse shadow bands. An object seen through such a mixing layer would have the appearance of one intermittently visible through a mechanical obstruction pierced with holes, as through the leaves of a tree, where the form of the object is thrown down in a great number of detached images. This seems to be the cause of the light spaces in the shadow bands, and in Chapter 3 it will be shown that the object seen in this way is the changing crescent of the disappearing or the appearing solar disk. Hence I have concluded that the shadow bands are simply a meteorological phenomenon, and have nothing to do with the diffraction of light around the edge of the moon.

THE WIND VELOCITY.

The wind velocities are recorded on Table 7 and Chart 10. The mean result is that the wind falls about 1 mile per hour on an average velocity of 6 miles. The groups 7, 8, and 9 show larger ranges than this, possibly 2 or 3 miles per hour. It should be noted, however, that all these stations are located on the South Atlantic or Florida coasts, and that there is probably something like a sea-breeze effect involved in this larger range. The winds during the eclipse blew from the south generally, as is seen by inspecting Table 8. This diminution of the wind velocity means a decrease in the current of air directed northward, which would be caused by imposing a southward component upon the northward stream. This remark seems to suggest that the wind variation is simply like an ordinary nocturnal effect, when the continental air, being chilled by the shadow, tends to flow toward the ocean areas. Thus the cooler air over the Southern States, as developed by the eclipse, produced a slight flow toward the Gulf of Mexico and to the Atlantic Ocean.

THE WIND AZIMUTH.

This quantity is given in Table 8 and Chart 11. The directions in azimuth are noted in the system adopted in the Cloud Report, page 138, where 0° azimuth is south, 90° east, 180° north, 270° west, and the direction is that *toward* which the wind is blowing. Thus a wind from the several quarters is given by the following azimuths:

From the N. is given by 0° azimuth.
" " W. " " " 90° "
" " S. " " " 180° "
" " E. " " " 270° "

Chart 11 shows that the variations in the azimuth were on the average very small during the eclipse, and the means seem to indicate that there was no definite change in the azimuth or direction of the wind which could be attributed to the eclipse. There is no sufficient indication of a real gyration which would require a change in azimuth on one side of the mean before the totality, and on the other side after the totality, in order to justify pursuing this subject further and drawing conclusions in that connection. This circumstance, together with the facts that the variation of the velocity is very slight and the change in the barometric pressure minute, seems to exclude the possibility that any sort of a true cyclonic circulation was generated by the action of the cooling effect of the moon's shadow on the atmosphere.

AMOUNT OF CLOUDINESS.

The cloudiness at several stations is given in Table 9, and the mean values indicate that a slight increase took place during the hour preceding totality, and that there was a relative clearing of the air during the hour following the totality. The range is about 0.3 on a scale of 10. There was no cloudiness observed at many of the stations, so that it was not possible to continue the same system of construction in groups as before.

GENERAL REMARKS.

Looking at the meteorological effects broadly, it is safe to conclude that there was a lowering of temperature by about 3° or 4° F., a lowering of the vapor tension by about 0.007 inch, and a decrease in the wind velocity by about 1 mile per hour, caused by the eclipse shadow. There was, on the other hand, no distinct cyclonic circulation of any kind, the observed motions of the air being due simply to relative land and water changes of temperature. Mr. Clayton has drawn a very different conclusion from his observations of this eclipse, to which I took an exception in my review of his report. It should be noted that in his formula for the computation of the prevailing wind azimuth he considers $\Sigma (\sin \theta)\, v$ equivalent to $\Sigma (v.\ \sin \theta)$, as shown by his example in Science, May 10, 1901. I was misled by his unusual notation into a misunderstanding of the computation. The latter was no doubt correct. Mr. Clayton's composite of his observations of the eclipse (Ann. Harv. Coll. Obsy., Vol. XLIII, Part 1, Pl. II, fig. 5) shows that he obtained an anticyclonic circulation of very large area at the center, bounded by a low pressure belt, and a feeble cyclonic circulation extending to a high pressure area on the outside of the edge of the moon's penumbra. Compare his pressure curves of Plate III. He seems to consider this an example of a cold center cyclone, and appeals to Ferrel's old conception of the circulation of the atmosphere over a hemisphere of the earth as an analogue to it. No attempt is made, however, to quantitatively justify this comparison of the eclipse circulation with that of the hemisphere, as should be done to render the illustration valid. For in the eclipse the difference of temperature is not more than 4° F., and the force of the wind is certainly less than 2 miles per hour; in the general cyclone there is a difference of temperature of about 80° F. on the average, and by Ferrel's theory of the conservation of areas the velocity of the wind near the poles should be enormously great. At any rate the entire energy of the solar radiation is engaged in maintaining a circulation of very great power and persistency over the earth. But even in the case of the northern hemisphere, the central anticyclonic movement is actually very feeble, and even nonexistent during at least half of the year, according to our modern observations.

There are only indecisive traces of a westward circulation near the pole during certain months. If the whole dynamic action of the hemisphere can produce merely temporary indications of an anticyclonic action within 20° of the pole, that is, extending to one-fourth the distance to boundary of the circulation, can it reasonably be admitted that the feeble variations observed in the eclipse will generate an anticyclonic circulation extending halfway to the outer limits of the total movement? For the coefficient of friction is approximately $k=0.00012$, and if $v=2$ miles per hour or 0.9 meter per second, then the contribution of surface friction to the dynamic equation is 0.00011, which can properly be neglected. The great disproportion between his central anticyclonic and the outer portions makes of the dynamic circulation an unbalanced machine that will not run without going to pieces.

Mr. **Clayton** reproduces in Science, May 10, 1901, p. 748, fig. 4, in the central zone a northeastward wind, but in all cold cyclonic movements the wind is outward at the surface from the pole to the boundary. **Ferrel** describes the wind of the central zone as composed of two components of which the primary is outward. There is a feeble current of air which he supposes to be squeezed out from under the high-pressure belt in opposite directions, and decreases the primary in the central zone, but increases it in the outer, that is in the one corresponding to the trade winds of the Tropics. **Ferrel** assumed that the secondary component keeps to the ground and that the primary overflows it at moderate altitudes (Amer. Journ. Sci., May, 1861; Recent Advances, p. 219, 1885), but since the publication of **Oberbeck**'s papers it has been seen that these components *merge into each other and produce a single resultant*, so that **Ferrel**'s figure has been abandoned. Compare **Sprung**'s meteorology, **Abbe**'s translations, **Bigelow**'s International Cloud Report, where these components of the general circulation are discussed. Aside from this, our recent observations, so far from confirming **Ferrel**'s old view, show that in the lower strata it must be greatly modified in order to match the actual circulation of the atmosphere. Finally, no true cyclone, including the anticyclone which surrounds it, can have the high-pressure belt near the outer periphery, as is indicated by Mr. **Clayton**; the high-pressure belt is theoretically located at seven-tenths of the distance from the center in warm cyclones and still nearer to it in cold cyclones. His analogue of the cold cyclone of the hemisphere to the eclipse circulation, therefore, can not be correct.

Besides the facts that our observations do not give any indication of a true cold center cyclonic circulation, and that Mr. **Clayton**'s result ascribes to the theoretically subordinate and usually unobserved polar component an undue influence, there is yet a more serious objection to his interpretation of his own data. Mr. **Clayton** assumes that the cold center circulation over a hemisphere of the earth is a true analogue to **Ferrel**'s cold center local cyclone, such as is supposed to be formed by the chilling effect of the moon's shadow in the earth's atmosphere, but he does not show that the boundary conditions are the same in each for the generation of that type of vortex motion. On the contrary, he states that the cyclonic circulation is propagated very rapidly, 2,000 miles per hour, through the atmosphere with the motion of the shadow. But, even though the air were chilled to a degree sufficient to generate a cold-center cyclone, *it could not produce such a circulation unless the same mass of air is constantly involved.* The hemisphere does possess such a confined mass of air, but **Ferrel** omitted to show that the local mass of air in nature, whether having a warm or a cold center, was thus bounded by an inclosing surface of any kind, as he assumed in his theoretical treatment of the problem. It is necessary that the same mass of air should be involved, as where in laboratory experiments the water in a cylindrical vessel is heated or cooled at the center. In this case the **Ferrel** cyclone is developed. It was **Ferrel**'s fatal error in constructing his theory of local cyclones that he did not show the existence in nature of such an outer bounding surface to a mass of air in gyration. To omit it and assume that the gyration would still continue of the same type is like pretending that a locomotive will work with the ends removed from the piston cylinders. The vortex type changes with the boundaries. The international cloud observations prove that the local warm-center cyclone involves fresh masses of air continuously; **Clayton**'s eclipse cold-center cyclone does the same thing; therefore the cold-center cyclone of the earth's hemisphere is not an analogue to either of these local cyclones. Meteorologists have been neglectful of this fundamental consideration in discussing cyclonic theories, namely, that the general and the local cyclones can not be analogues of each other unless it is shown that the mass of air once involved in the circulation remains identical throughout the duration of the movement. Hence, Mr. CLAYTON's endeavor to establish such an analogue between the general cyclone and the eclipse cyclone is in reality fatal to his own hypothesis that the transit of the moon's shadow through the atmosphere can produce such a cold-center cyclone as he claims to have discovered. His further deductions regarding the diurnal barometric wave are of course involved in this untenable supposition.

It is only necessary to add a single remark regarding the relations of the local cold-center and the warm-center cyclones. These cyclones have each the same direction of rotation in horizontal planes about the vertical axis, but they differ from one another in that the vertical circulation is in opposite directions. They conform to strict mechanical principles involving closed circuits for the stream lines, and the continuous flow of the same mass of liquid. The anticyclone is, on the other hand, the product of the interference of two independent currents of air and it rotates in the opposite direction to that of the cyclone. It does not contain a system of closed circuits in itself. That is to say, having a mass of liquid in a cylindrical vessel, it is not possible by heating or cooling the central portions to generate an anticyclone. Hence the eclipse shadow could not by chilling the air in a cylindrical tube make so large an anticyclonic circulation near the center as Mr. CLAYTON has indicated. A feeble modification of the normal pressure in a cold-center cyclone might be produced near the axis when there is a large velocity of rotation and much friction. I do not here renew the question as to what extent the FERREL local cold or warm center cyclones really exist at any time in the circulation of the atmosphere, for I have elsewhere stated that it seems to be merely an ideal circulation, having little application in practice, except to some extent in the tropical hurricanes. It is perhaps unfortunate that so well-conducted eclipse meteorological observations as those of May 28, 1900, when the air was quiescent, so far as local cyclonic circulations are concerned, should yet have failed to show distinctly an appreciable change in the barometric pressure. For under the given circumstances the uncertainty of eliminating the diurnal and the cyclonic pressures from the eclipse pressure was at a minimum. The result, of course, throws great doubt upon the records of other eclipses which are supposed to have given pressure disturbances worthy of consideration At all island and seacoast stations there will occur during an eclipse a sea-breeze phenomenon, with a wind velocity in contrary directions, and an alternate-change of barometric pressure. It is quite likely that this has been interpreted as an eclipse wind in some cases. The records of this eclipse for 62 stations are produced in full, with the purpose of permitting all to see how unsafe it is to draw conclusions from the indications of a few eclipse stations, as can be done by comparing the individual stations with the means of the groups or with the general means. An observer might have some local movements which it would be possible to interpret as an eclipse action, but in general the wind effect is very slight. Nor am I able from our records of the wind to detect any special change in the wind direction due to the eclipse proper. Since the velocity is a little greater before the shadow reached a given point and less after it has passed, and considering that the prevailing southwest wind, that is, a vector motion to the northeast, is feebly accelerated in front but retarded in the rear of the shadow, it is evident that this is equivalent merely to an outward flow on all sides from the entire region covered by the shadow. That is also a very natural conclusion to be drawn, judging from the entire set of circumstances. The shadow near the surface is about 4° colder than the surrounding atmosphere, and the denser air would naturally stream outward radially for a short distance. If the movement is so slight as a mile per hour relative to the undisturbed motion of the air, yet there may be produced by this means a set of ripple waves in circles surrounding the shadow. These ripple waves must have something to do with the fluttering movement observed in the shadow bands. Furthermore, the temperature disturbance in the atmosphere should be confined to the lower strata, if not to a thin stratum near the ground, because, as in the case of the diurnal range of temperature, it is only the stratum a mile or so in thickness near the surface of the earth which is notably affected by the diurnal variation of the solar radiation. It seems probable that the feeble outflow just described is something like a weak thunderstorm squall rush, and occurs very low down. The consequence of this supposition is that the ripple wave formation may be practically a surface

phenomenon and may not involve the upper layers of the atmosphere, because in this region the fall of temperature due to the shadow can not be very large. The shadow cast by the earth during the night is entirely comparable to that cast by the moon during the eclipse so far as the action of the laws of radiation are concerned, and we know that the nocturnal shadow does not disturb the temperatures of the upper strata very much. This is due to two facts: (1) that the air radiates slowly as compared with the ground, and (2) that the rapid motion of the upper strata causes the process of mixture to be very effective in the higher levels. We can not expect to detect any inflow of the higher strata into the moon's shadow corresponding to the outflow at the surface, because the movement is much too feeble for any such purpose.

THE NUMBER OF CALORIES, PER KILOGRAM, ABSORBED AT THE EARTH'S SURFACE BY THE SHADOW.

The real reason for which the differential values of the pressure, temperature, and vapor tension, between the undisturbed diurnal values and the values observed during the eclipse have been obtained, was to facilitate a computation of the amount of heat cut off from the earth by the temporary presence of the moon's shadow. These data will have a bearing upon the problem of the absorption and radiation of heat by the earth's atmosphere, since the shadow of the moon during the eclipse was merely a localized space into which the heat already in the atmosphere could escape. It may be considered a restricted sort of nighttime. The use that may be made of the result depends upon the specific problem which is to be discussed. The method of computation followed is that laid down in the International Cloud Report, Weather Bureau, 1898–99, and the formula is found on page 785, the Tables 95, 96 being employed for the necessary reductions. Table 10 gives an exhibit of the work, and it begins with the data included in the

TABLE 10.—*Computation of the calories per kilogram of air absorbed by the moon's shadow near the ground in the total solar eclipse of May 28, 1900.*

	10 −30	11 −15	12 −5	13 Total	14 +5	15 +15	16 +30	17 +45	18 +60	19 +75	20 +90	21 +105
Normal B_n	29.76	29.78	29.79	**29.80**	29.81	29.83	29.84	29.87	29.90	29.92	29.93	29.93
Shadow B_s	29.76	29.78	29.79	29.80	29.80	29.80	29.79	29.81	29.88	29.92	29.93	29.93
T_n	72.3	72.9	73.3	**78.5**	73.7	74.2	74.8	75.5	76.2	76.8	77.4	7.81
T_s	72.3	72.0	71.4	71.3	71.3	71.1	71.4	72.2	73.6	75.4	76.8	7.81
e_n	.576	.580	.577	**.576**	.575	.577	.580	.581	.585	.581	.577	.577
e_s	.576	.578	.573	.571	.569	.570	.573	.575	.582	.581	.577	.577
						THE DIURNAL ELEMENTS.						
B_n	755.91	756.41	756.67	756.92	757.18	757.68	757.94	758.70	759.46	759.97	760.22	760.22
t_n	22.39	22.72	22.94	23.06	23.17	23.44	23.78	24.17	24.56	24.89	25.22	25.61
e_n	14.63	14.73	14.66	14.63	14.61	14.66	14.73	14.76	14.86	14.76	14.66	14.66
$\frac{e}{B}$	.00193	.00195	.00194	.00193	.00193	.00193	.00194	.00195	.00196	.00194	.00193	.00193
Ia	1.35215	1.35242	1.35259	1.35269	1.35277	1.35298	1.35326	1.35359	1.35391	1.35415	1.35441	1.35473
IIa	.45486	.45491	.45493	.45495	.45498	.45502	.45504	.45511	.45518	.45523	.45543	.45543
A=Ia−IIa	.89729	.89751	.89766	.89774	.89779	.89796	.89822	.89848	.89873	.89892	.89898	.89930
						THE SHADOW ELEMENTS.						
B_s	755.99	756.41	756.67	756.92	756.92	756.92	756.67	757.18	758.95	759.97	760.22	760.22
t_s	22.31	22.22	21.89	21.83	21.83	21.72	21.89	22.33	23.11	24.11	24.89	25.61
e_s	14.63	14.68	14.55	14.50	14.45	14.48	14.55	14.61	14.78	14.76	14.66	14.66
$\frac{e}{B}$	.00193	.00194	.00192	.00192	.00191	.00191	.00192	.00193	.00195	.00194	.00193	.00193
Ia	1.35215	1.35203	1.35173	1.35169	1.35168	1.35160	1.35174	1.35210	1.35275	1.35358	1.35324	1.35473
IIa	.45486	.45491	.45493	.45495	.45495	.45495	.45493	.45498	.45514	.45523	.45543	.45543
B=Ia−IIa	.89729	.89712	.89680	.89674	.89673	.89665	.89681	.89712	.89761	.89835	.89781	.89930
$B-A$	.00000	−.00039	−.00086	−.00100	−.00116	−.00131	−.00141	−.00136	−.00112	−.00057	−.00017	.00000
$273+\frac{t_n+t_s}{2}$	295.4	295.5	295.4	295.4	295.5	295.6	295.8	296.3	295.8	296.5	298.1	298.6
Calories	0.000	0.115	0.254	0.295	0.343	0.387	0.416	0.403	0.331	0.169	0.051	0.000

columns 10 to 21 of the preceding compilation of the observations taken during the eclipse. The arguments are placed at the side of the table, and now the actual values of the elements as determined for the normal curves and the shadow curve can be constructed from the curves. These are entered in Table 10, $B_n \,.\, t_n \,.\, e_n$. for the undisturbed diurnal curve of May 28, 1900, and as $B_s \,.\, t_s \,.\, e_s$. for the shadow curve of that date. They are scaled from the curves and are entered in English measures. In the case of the pressure the shadow curve shows a general drop on the other groups, which is not an eclipse effect, and it is included, as the influence on the computation is very slight. The differences $B_n - B_s$, $t_n - t_s$, $e_n - e_s$ are the same as the shadow variations found at the end of the respective tables of the three elements, so that the data are in harmony with the preceding discussion. These data are now transformed into metric measures, and the diurnal elements and the shadow elements are collected in separate groups. The ratio $\frac{e}{B}$ is computed for the several sets. The formula for the computation of the calories per kilogram required to transform a kilogram of air under certain conditions ($B_n \,.\, t_n \,.\, e_n$.) into another condition ($B_s \,.\, t_s \,.\, e_s$.) is as follows:

$$\int \frac{dQ}{T} = (\lambda c_p + \mu c'_p) \log \frac{T}{T_o} - A(\lambda R + \mu R_1) \qquad \log \frac{p}{p_o}, \qquad \text{or, in another form,}$$

$$\int dQ = Q = T\left[\left(.2374 + .1512\frac{e}{B} + .0232\frac{e^2}{B^2}\right) \log T - \left(.06858 + .02592\frac{e}{B}\right) \log B\right]_n$$
$$- T\left[\left(.2374 + .1512\frac{e}{B} + .0232\frac{e^2}{B^2}\right) \log T - \left(.06858 + .02592\frac{e}{B}\right) \log B\right]_s,$$

where the first line refers to the diurnal and the second to the shadow elements. The first terms in each line are the same as I_a in Table 65, and the second the same as II_a in Table 66. It is not necessary to go beyond this point in the discussion, because the elements remain throughout in the unsaturated α stage. Since the range in the temperature is small—that is, less than 4° F., it is proper to take the mean temperature $t = \frac{t_n + t_s}{2}$ for the several sets to be computed. With the arguments $\left(t, \frac{e}{B}\right)$ take out I_a, and with $\left(B, \frac{e}{B}\right)$ take out II_a. Subtract the values for A and B in the diurnal and the shadow respectively. Since A is the undisturbed value and B the value which occurs in consequence of the transit of the shadow, the difference, $B - A$, is the loss of heat caused by the radiation into the shadow during its presence at a given station, and it is the mean or the representative of the entire system of observations. Multiply the values $(B - A)$ by T, as computed for each set, and we obtain the number of calories of heat absorbed by each kilogram of air. Since a kilogram is equivalent to about seven-tenths of a cubic meter of air at the earth's surface, these are the amounts absorbed by this volume. Hence, one can compute, if desired, the total amount absorbed by the shadow, in a layer one meter thick, and throughout the entire cone as limited by any assigned upper layer, provided the proper variation of the absorption with the elevation is known. Such an extension of the problem involves several quantities which are not now available.

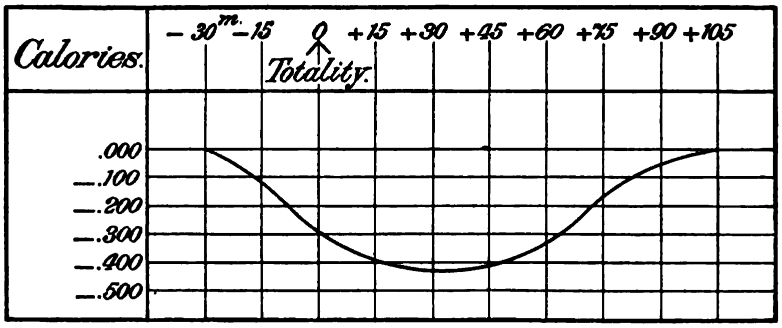


CHART 12.—The number of calories per kilogram absorbed by the moon's shadow May 28, 1900.

Chart 12 gives a graphic representation of the result of the computation, and it shows that beginning with column 10, 30 minutes before totality, the number of calories absorbed increased to 4.40 at 15 minutes after totality, and then decreased to zero at about 93 minutes after the totality. From 15 minutes after totality to 45 minutes after totality there was very little change, and I regard 30 minutes after totality as the moment of the true maximum. This divides the curve into two nearly equal parts, and gives 45 minutes for the absorption of the heat and about 45 minutes for the return to a normal diurnal condition of the atmosphere. The amount of heat required to transform the shadow kilogram into the diurnal kilogram is about half that required to transform an adiabatic kilogram into the same diurnal kilogram. I think that the gradual collection of such data as the foregoing will throw valuable light upon the problem of atmospheric absorption and radiation, and that in future eclipses efforts should be made to conduct the meteorological observations on as large a scale as is practicable, instead of confining them exclusively to the eclipse stations.

CHAPTER 3.

THE OBSERVATIONS ON THE SHADOW BANDS AND DISCUSSION OF THE RESULTS.

THE INSTRUCTIONS FOR THE OBSERVATION OF THE SHADOW BANDS.

In order to secure observations on the phenomenon of the shadow bands, which are seen just before the total eclipse occurs and also just after the shadow passes an observer stationed in the path of the totality, a suitable set of instructions for conducting the work was issued by the Weather Bureau. This form was distributed to many persons located in the shadow path, who volunteered to make the necessary preparations and record the results, and replies were received from 40 or 50 persons, either giving some data or else stating that they were unable to secure the observations. The following report is based upon the work of 34 observers who have contributed important facts bearing upon the phenomenon in question. A copy of the instructions and the form for recording the results is added in order to show exactly what it was that the observers attempted to perform.

METEOROLOGICAL OBSERVATIONS DURING THE TOTAL ECLIPSE OF THE SUN MAY 28, 1900.

U. S. Department of Agriculture, Weather Bureau,
Washington, D. C., May 15, 1900.

By direction of the Chief of the Weather Bureau, the following special meteorological observations will be taken during the hours of the eclipse of the sun, May 28, 1900, at the stations receiving this order:

It is particularly important to set the clocks and sheets of all the self-registering apparatus as accurately as possible before the time of the eclipse, and have the pens in perfect working order.

The inclosed form for the original records is practically the same as Form No. 1001-Met'l, and the observations are to be made precisely as usual, but with all possible care to avoid personal equation in the readings, at the minutes of seventy-fifth meridian time indicated on the margin. The correction for elevation need not be applied at the station, and the column marked "Ratio $\frac{e}{B}$," will be left blank. In case it is not convenient to make all these observations very near the minute indicated, then the observers should subdivide the work so that each set shall be practically simultaneous at the appointed time. The wind direction and velocity, also the direction and motion of all kinds of clouds visible, are required as carefully as possible. Under remarks on the state of the weather note clearly all circumstances attending the progress of the eclipse, but the space on the form may be used simply to make references to more extended notes, which will be filed with this report.

The observations will probably indicate a fall in temperature and increase in relative humidity; a backing of the wind for a time followed by a veering; possibly a small change in the pressure, if it can be distinguished from the diurnal range and from the local cyclonic movements. It is desirable that these observations be continued hourly till the 8 p. m. regular observation, but they are voluntary beyond the times specified on the forms.

THE SHADOW BANDS.

The observations on the shadow bands are voluntary at all the Weather Bureau stations, but it is hoped that the method of observing them may be explained to persons who will cooperate with the Weather Bureau officials by undertaking them. Such work on the bands should be carried on at as many places as possible throughout the region covered by the track of totality, but they are more valuable along the edges than on the central line.

Just before and just following the instants of totality—that is, the second and third contacts—a series of shadow bands pass over the ground, in different directions at the two contacts. It is very important to observe the following points regarding them: (1) The direction of motion, which is that perpendicular to the bands themselves; (2) the velocity of motion; (3) the number of bands and light spaces per yard; (4) the study of flickering characteristics and other physical aspects that they may present. It is necessary to make these observations as follows: Smooth a piece of ground carefully and fasten a large white sheet without wrinkles so that the edges shall be oriented exactly N. to S. and E. to W.; lay down a straight stick 2 yards long parallel to the bands at the first appearance of them before the totality and leave it in place, and then another stick when they appear again after totality; measure the exact angle between these sticks, and between each of them and the true north and south line; provide a board 2 yards long painted black and white in alternate feet, making three black spaces and three white spaces, and lay it down in the direction the bands are running; count the number of bands seen on the whole or a portion of this board as is convenient and easy to do with accuracy, and thus estimate the width of the bands and of the light spaces, respectively; run alongside the bands at an equal pace with their motion and determine by comparison with a measured distance the velocity in the number of feet per second. Note any peculiarities of the bands actually seen and not imagined. It will probably be possible to secure the assistance of others, so that the several parts of this work may be assigned to different persons, and confusion should be avoided by sufficient preliminary practice. Much will depend upon the good judgment of the observers. These eclipse bands are to be seen most favorably near the edges of the shadow of the totality, and it is much to be hoped that persons who happen to be in such places may be induced to cooperate in this special observation. Your knowledge of the locality may enable you, by your correspondence, to secure the services of several such parties.

All the records should be mailed to the central office exactly as originally made and without modification when once the figures are entered. Supposed mistakes may be referred to by means of side notes and special remarks.

WEATHER BUREAU OFFICES HAVING ONLY ONE REGULAR OBSERVER.

Whenever there is only one observer at a station all the observations here indicated which will interfere with the necessary duties of the station, such as the taking of the morning observation, the preparation of the map, the distribution of the forecasts, etc., will be omitted, but all the data which can be acquired outside this limitation should be entered and transmitted. In these stations reliance must be placed on the self-registering apparatus, but it is always preferable to read the standard instruments.

Respectfully,

Frank H. Bigelow,
In Charge of the Eclipse Observations.

For Volunteer Observers.

[Form for observing the shadow bands of the total eclipse of the sun May 28, 1900.]

Watch carefully for the time when the first thin crescent is disappearing for the beginning of the bands; the bands may be expected three minutes earlier.

BEFORE THE TOTALITY.

1. Note time (local or 75th meridian) of beginning: Hour minute second . Corrected time should be entered in all cases.
2. Direction of bands parallel to the first stick: Degrees minutes from N. to S. line; recorded north with degrees east or west.
3. Number of bands in a yard: bands; light spaces.
4. Relative width of the bands and spaces: The bands were as the spaces.
5. Velocity of motion of the bands by pacing: The bands moved feet per second.
6. Note time when the bands disappeared: Hour minute second

AFTER THE TOTALITY.

7. Note time (local or 75th meridian) of beginning: Hour minute second .
8. Direction of bands parallel to the second stick: Degrees minutes from N. to S. line.
9. Number of bands in a yard: bands; light spaces.
10. Relative width of the bands and spaces: The bands were as the spaces.
11. Velocity of motion of the bands by pacing: The bands moved feet per second.
12. Note time when the bands disappeared: Hour minute second .

It should be noted that the form itself required simply the direction in which the bands themselves lay, as referred to a north and south line, and this was done in order to avoid confusion of the direction of the bands with the direction of the motion, which was usually at right angles to the bands. After the replies had been examined, a letter of inquiry was addressed to the several observers requesting further information regarding the direction of the motion as an independent fact. The letters in return contained interesting and important remarks on the appearance of the bands, some of which have been reproduced for further examination in studying the theory of the cause of the shadows themselves. Extracts from the reports are incorporated at this place for the guidance of the reader.

NOTES ON THE DIRECTION OF MOTION AND THE APPEARANCE OF THE SHADOW BANDS.

Virginia Beach, Va.—Some little difficulty was experienced in determining in just what direction the bands were moving; that is to say, whether southwest or northeast. My impression of the bands was that there was more than one set and that they may have been moving in diametrically opposite directions. The effect was very like that of walking parallel to a double line of picket fence and observing the flicker and apparent contrary movement caused by the shifting of the relative positions of the lights and open spaces. In addition to this flicker of the bands there seemed to be a regular transverse sliding of the bands, which gave the effect that a third set of bands would give if superimposed upon the others and made invisible in some way in the light spaces. It has seemed probable to me that there may have been a considerable number of sets of bands, but the illumination being from practically a slit (a crescent of only a few degrees in arc), only those that lay parallel to it would be clearly defined.—GREENLEAF W. PICKARD.

Monticello, Ga.—The bands or shadows were not continuous, but veering, undulating, and flickering. The motions of the bands were flickering, zigzag, and partly indistinct, moving rapidly. It was impossible to measure their velocity.—C. H. JORDAN.

Lancaster, S. C.—The shadow bands were moving northeast before and southwest after totality, not exactly in an inverse direction, but more south of west and north of east.—T. H. DAVIS.

Three miles east of Lancaster, S. C.—At their second appearance the bands were moving in the same direction—viz, toward northeast—as at the first appearance. Near the time of second contact there was a mingling of light and dark upon the sheet a few seconds before the bands themselves appeared. The bands were wavy and irregular in character and were too dim to be seen on the board divided into foot spaces. Mr. CULP describes the bands as irregularly and finely chopped up shadows moving over the sheet at about the speed of the flickerings noticed in a "cinematograph" or "vitascope" picture when poorly projected on a screen. Miss COOK describes the bands as parallel, wavy, dark bands about an inch wide. She insists that about two minutes after the second set of bands disappeared she noticed a third set of bands upon the sheet extending parallel with its longer edge—that is, N. 18° W. magnetic and moving westward.—CLEVELAND ABBE, Jr.

Longshore, S. C.—The shadow bands moved to the northeast before totality; also in the same direction after totality. The strangest thing about the eclipse was the flashes of light playing on my sheet just after the shadow bands commenced and before they ceased to move. It had the appearance of a flash made by the sun on a small round looking-glass and had the shape of a small horseshoe. It played over the sheet rapidly just before the bands commenced to move and then just as they ceased after totality.—W. G. PETERSON.

Polkton, N. C.—Before totality the bands moved from southwest toward northeast; after totality they were very indistinct, but seemed to move from nearly southeast toward northwest. The bands were very obscure and hard to see on a white sheet. At places 8 or 10 miles away they were very apparent anywhere on the earth's surface. They traveled rapidly, seemingly as fast as a bird flies.—W. F. HUMBERT.

Morgan City, La.—We could not get the velocity of the bands nor the number of the bands per yard. The bands quivered to the extent of dazzling the eyes.—B. M. YOUNG.

Spring Hope, N. C.—The bands moved in the same direction—that is, northeast—before and after totality. The bands were not straight, but curved almost crescent shape.—GEORGE W. BUNN.

Raleigh, N. C.—Just before totality the bands seemed to me to consist of narrow pencils of light and shadow extending directly from west to east and appearing to move directly from west to east in the direction of their length. After the totality the bands were so faint that the direction in which they lay and their movements could not be determined. I received the impression that they lay from northwest to southeast, but moved from west to east.—C. F. VON HERRMANN.

Raleigh, N. C.—The bands flickered and moved so that it was rather difficult to estimate their number and velocity of motion.—B. IRBY.

Auburn, Ala.—No shadow bands were seen, or, if so, it might be imaginary. I had five men to assist me and none of them saw anything.—TROY POOL.

Auburn, Ala.—The bands were indistinct, flickering, and apparently darkest at the rear edge, shading out gradually to the light band next in front. In their movement they gave the sheet the appearance of being in motion similar to that produced by a strong current of air blowing under it, or like it was being shaken rapidly from one side. This condition was so marked as to deceive persons standing about, and one gentleman remarked that the strong breeze which sprung up about the time of totality had gotten under our sheet. On the second appearance of the bands it was observed that they changed direction of motion. When they first started they were moving almost due east, but at the end of their appearance they had changed through an angle of about 13° to the north. We have no definite observation to indicate that the first set changed direction, but I have an impression that they did change slightly from a little west of north to a little east of north.—JOHN J. WILMORE.

Santuck, S. C.—The bands were very dim, looking like thin smoke passing over the sheet, and we could not distinguish well enough between the bands and light spaces, but estimate the bands were about 2 inches wide. I noted the peculiar look and shape of the shadows of tree leaves before the totality, which were crescent shape and as if in two lights, sending rays across each other. Before totality the bands were moving slightly to the west of north. After totality they moved toward east by south.—E. W. JETER.

Louisburg, N. C.—Before totality the bands were very nearly due east and west, the line of motion being to the north. (It may be that it was very slightly toward the east, but, as said above, the bands were nearly due east and west.) Afterwards they were at right angles with the first, and the line of motion was toward the east. There was an appreciable fall of temperature and a deposit of dew; a peculiar yellow appearance of everything, and the shadows were unusually shaped. I was told by a party who saw the bands at Youngsville that they were north and south just before totality. He was somewhat frightened, according to his version, by the dust moving on the ground although there was no wind. I take it that the dust mentioned was the shadow bands.—THOMAS B. WILDER.

Albemarle, N. C.—The shadow bands moved to the northeast before totality and to the southwest after totality. They began to flicker across the ground just before the second contact, coming from the direction indicated, and changed rapidly around by the west to the northeast without stopping. They were indistinct, flickering, about 1 to 2 inches wide, and were traveling at a rapid rate.—G. M. DRY.

Elberton, Ga.—The shadow bands passed over in one direction N. 30° W. before totality and in the opposite direction immediately after totality.—H. A. ROEBUCK.

Senoia, Ga.—The first bands pointed east and west and moved north; after totality they pointed from northwest to southeast, but moved exactly to the northeast. They were flickering and very unsteady and traveled so fast that it was impossible to pace them, nor could we tell their relative size or the number of bands in a yard.—W. R. McCRAY.

Little Mountain, S. C.—The shadow bands were apparently only a fraction of an inch in width, with a dancing, shimmering motion, whose velocity could not be estimated. It had something of the appearance of a back-and-forth motion. The bands extended N. 50° W., according to my measurements, and were the same in direction before and after totality. The general direction of motion before totality was to the northeast. I am not sure whether or not the motion was reversed after totality, but think it was not.—L. C. GLENN.

Hobgood, N. C.—The little shadows ran over a sheet so dim and fast that I could not make any calculations.—IVEY M. PARKER.

Bay St. Louis, Miss.—I noticed the shadow bands about a minute before totality and a minute after, but their precise direction, their number per foot, and their velocity could not be ascertained on account of shortness of duration—two or three seconds each time. They appeared to move in curved lines, 1 to 2 inches thick, in a southwest direction before and in a northeast direction after totality.—BRO. ISIDORE.

Wilson, N. C.—The bands were too indistinct at first contact to admit of any calculations. At the second contact the bands were of a flickering nature, following one another at regular intervals, bearing to the light spaces the ratio of 1:4 in width.—H. H. HUTCHINSON.

Cheraw, S. C.—The first appearance of the bands before totality was very faint and indistinct and hard to discern in their motion, but I am strongly under the impression that they moved from northeast to southwest. The bands after totality were quite visible and easily discerned, and they moved from south to north. The bands moved at a very rapid rate, and the time was so short that it was not easy to see everything about their movement. They moved in a wavy and flickering manner as they appeared to the eye.—H. L. LOUGHLIN.

Biloxi, Miss.—No bands were visible before totality. The bands were observed after totality very indistinctly, running or moving from north to south, but too quick for thorough observation or measurement. They flickered badly.—J. J. LEMON.

Batesburg, S. C.—The bands ran in opposite directions—before totality northeast and after totality southeast or slightly more toward the south.—E. J. HITE.

The bands were reported to have been seen at Montgomery, Ala., at Columbia, S. C., just to the south of the line of totality, and also at Charleston, S. C., but no very definite observations were made of them at those places.

Out of these observations we may summarize the following facts on the general appearance of the bands: These had, (1) a flickering, wavy, and unsteady motion, noted generally, but specifically at Virginia Beach, Va., Monticello, Ga., Lancaster, S. C., Raleigh, N. C., Auburn, Ala., Albemarle, N. C., Little Mountain, S. C., Wilson, N. C., Cheraw, S. C.; (2) the velocity and other conditions could not be measured on account of their unsteadiness at Monticello, Ga., Polkton, N. C., Morgan City, La., Raleigh, N. C., Senoia, Ga., Little Mountain, S. C., Hobgood, N. C., Bay St. Louis, Miss., Biloxi, Miss.; (3) there was a mingling of light and shade a few seconds before the bands appeared at East Lancaster, S. C.; (4) there seemed in two cases, at

Virginia Beach, Va., and at Santuck, S. C., to be a superposition of two or even more sets of separate bands; (5) the shape of the bands was described as follows just before and just after totality: As horseshoe shaped at Longshore, S. C.; as crescent shaped at Spring Hope, N. C.; as having curved lines at Bay St. Louis, Miss.; as darkest on the rear edge at Auburn, Ala.

From all this we draw the conclusion that the shadows were crescent shaped, and had a flickering motion as if struggling through two or more conflicting movements in the atmosphere itself. It may be stated here by way of anticipating a part of the view to which we have come regarding the physical origin of the shadow bands, that there seem to be decisive arguments against the idea that they are a diffraction phenomenon in any way. On the other hand, the images of the sun, or the partial disks which are seen on the ground underneath the leafy foliage of a tree, projected through the light spaces between the leaves, seems to be a suggestive picture of the process which is involved. We have here several independent observations that the bands had a crescent shape, like the disappearing or the appearing thin crescent of the sun at the second and the third contacts, respectively. We hope to show that the edges of the umbra for a considerable distance from the theoretical geometrical edge is in reality made up of patches of shadow and patches of light, caused in part by the meteorological air currents of the upper and lower strata, and by the thrusting into the atmosphere of a distinctly colder cone, which sets up undulations and disturbances near its surface that must influence the appearance of the rays of light passing through them. The separate flickering bands may be thus referred to the independent air currents of the atmosphere, and the irregular absorption, refraction, and reflection of light on the roughly constructed edge of the umbra may be likened to the effect of the broken foliage on the sun's image, whereby a multitude of separate disks are produced on the ground beneath it. In this way the single thin crescent of the sun at the moment before totality, by passing through such a semiopaque medium which must surround the umbra, may be multiplied into numberless images, and these would also possess the wavy and flickering features so uniformed ascribed to them by many observers. Without attempting to further explain this view at this point, we will pass on to a further description on the observations, which seem to point strongly if not conclusively to this general idea.

THE OBSERVATIONS ON THE SHADOW BANDS BEFORE AND AFTER TOTALITY.

The observations on the shadow bands have been collected in two tables, 11 and 12, the first before totality and the second after totality. In these tables the stations are separated into two groups, the first containing those which are located north, and the second those which are south of the central line of the shadow path, the former having 20 and the latter 10 stations. About 50 stations or observing parties reported to the Weather Bureau, but only those included in the tables had valuable results. The first column contains the stations; the second the observer's name; the third the relative distance from the center, on the supposition that the radius of the shadow path is equal to 100; the fourth column gives the direction in which the bands were observed to lay upon the ground, and the fifth that toward which the bands as a group appeared to be moving; the sixth gives the velocity of their motion in feet per second; the seventh column contains the width of the dark bands in inches, and the eighth that of the light spaces; the ninth gives the observed time when the bands were first seen; the tenth the time when they disappeared, and the eleventh the apparent duration. The material from which these tables were constructed makes it very evident that the observers had been laboring under great difficulties in their attempts to make definite observations on the shadow bands.

Table 11.—*Observations made on the shadow bands at the eclipse of May 28, 1900.*

BEFORE TOTALITY.

Station	Observer	Distance center. Rad. = 100	Direction of bands	Direction of motion toward	Velocity of motion	Width of bands	Width of spaces	Begins	Ends	Duration
								75th meridian time		
NORTH			°	°	*Ft. per sec.*	*Inches*	*Inches*	*h. m. s.*	*h. m. s.*	*m. s.*
Virginia Beach, Va.	Pickard	5	N 32 W	S 43 W	8	1.5	2.5	8 50 30	8 52 46	[2 16]
Newberry, S. C.	Houzeal	10	....	....	....	....	....	....	....	....
Monticello, Ga.	Jordan	11	N 18 W	NE	....	1.0	1.0	8 40 27	8 41 43	[1 16]
Winton, N. C.	Daniel	15	N 44 W	....	Fast	1.5	1.5	8 50 26	8 50 41	0 15
Lancaster, S. C.	Davis	25	N 56 W	N 31 E	15	One-third as wide		....	8 43 0	....
	Wallace	25	N 50 W	NE	10	About as wide		8 49 0	....	....
	Wilds	25	N 41 W	NE	10	1.0	1.0	....	....	....
	Norris	25	N 30 W	E	....	....	....	8 44 10	....	....
Longshore, S. C.	Peterson	31	N 40 W	N 50 E	....	....	....	....	....	....
Polkton, N. C.	Humbert	34	....	NE	Rapid	....	....	....	....	....
Morgan City, La.	Young	38	N 86 W	....	....	1.5	1.5	8 28 27	....	....
Springhope, N. C.	Bunn	42	N 66 W	NE	2	1.5	2.0	....	....	....
Raleigh, N. C.	Von Herrmann	45	N 90 W	E	....	....	....	8 47 ..	8 49 ..	....
	Irby	45	N 76 W	....	.3	1.0	1.5	8 47 42	8 48 ..	....
Auburn, Ala.	Wilmore	71	N 88 W	N 2 E	11	5.0	10.0	8 36 25	8 36 35	0 10
Candor, N. C.	Hight	73	N 49 W	....	2.5	0.5	2.5	....	8 20 15	....
Santuc, S. C.	Jeter	75	N 71 E	N 20 W	....	2.0	2.0	8 9 51	....	....
Wake Forest, N. C.	Lanneau	77	N 85 W	....	....	....	....	....	....	....
Louisburg, N. C.	Wilder	88	N 90 W	N	5	1.0	4.0	8 47 49	....	....
Rock Hill, S. C.	Culp	97	N 92 W	N	....	1.5	1.5	....	....	....
Mount Willing, Ala.	Garrett	98	N 85 W	N	4	1.0	4.0	8 37 22	8 37 30	0 8
Albemarle, N. C.	Dry	100	N 60 W	NE	Rapid	1.5	1.5	8 44 ..	....	....
Elberton, Ga.	Roebuck	100	N 60 E	N 30 W	6	3.0	3.0	8 47 ..	8 47 30	....
Senoia, Ga.	McCray	110	N 90 W	N	....	0.5	0.5	8 38 ..	8 38 30	....
SOUTH										
Rockingham, N. C.	Stansill	17	....	....	6	0.5	0.5	8 45 15	8 45 30	0 15
Little Mountain, S.C.	Glenn	25	N 50 W	NE	....	0.5	0.5	....	....	....
Hobgood, N. C.	Parker	30	NW	NE	....	....	....	8 48 ..	....	....
Bay St. Louis, Miss.	Br. Isidore	36	NW	SW	....	1.5	1.5	....	....	....
Selma, N. C.	Noble	42	N 45 W	NE	....	2.0	2.0	8 48 0	....	....
Wilson, N. C.	Hutchinson	44	N 100 W	....	....	....	....	8 44 30	8 49 30	....
Cheraw, S. C.	Loughlin	58	N 52 W	SW	7	0.5	3.0	8 45 54	8 46 0	0 6
Biloxi, Miss.	Lemon	64	....	....	....	....	....	....	....	....
Belcross, N. C.	Godfrey	80	N 5 E	....	3	1.0	1.0	8 54 10	8 54 30	0 20
Batesburg, S. C.	Hite	95	NW	NE	6	0.5	1.0	....	8 42 0	....
Means		....	....	....	6.6	1.37	2.15	....	....	12.3
Averages		....	....	....	6.45	1.30	2.20	....	....	13.3
						3.50				

TABLE 12.—*Observations made on the shadow bands at the eclipse of May 28, 1900.*

AFTER TOTALITY.

Station	Observer	Distance center Rad. = 100	Direction of bands	Direction of motion toward	Velocity of motion	Width of bands	Width of spaces	Begins	Ends	Duration
								75th meridian time		
NORTH			°	°	*Ft. per sec.*	*Inches*	*Inches*	*h. m. s.*	*h. m. s.*	*m. s.*
Virginia Beach, Va.	Pickard	5	N 42 W	S 43 W	8	1.5	2.5	8 54 21	8 56 30	[2 9]
Newberry, S. C.	Houzeal	10	N 48 W	NE	7	1.0	2.0	....	....	0 10
Monticello, Ga.	Jordan	11	N 31 W	SW	4	0.5	1.5	7 43 14	7 43 26	0 12
Winton, N. C.	Daniel	15	....	....	....	....	....	....	....	....
Lancaster, S. C.	Davis	25	N 32 W	S 20 W	....	One-third as wide		8 44 1	8 44 10	0 9
	Wallace	25	N 50 W	NE	10	Same width		....	....	....
	Wilds	25	N 41 W	NE	10	1.0	1.0	....	....	....
	Norris	25	N 30 W	E	....	....	....	....	....	....
Longshore, S. C.	Peterson	31	N 40 W	N 50 E	....	....	....	....	....	....
Polkton, N. C.	Humbert	34	....	NW	....	....	....	....	....	....
Morgan City, La.	Young	38	N 26 W	....	....	1.5	1.5	8 30 24	....	....
Spring Hope, N. C.	Bunn	42	N 61 W	NE	2	2.0	3.0	....	....	....
Raleigh, N. C.	Von Herrmann	45	N 45 W	E	....	....	....	....	....	....
	Irby	45	N 43 W	....	3	0.7	1.5	8 49 42	8 50 57	[1 15]
Auburn, Ala.	Wilmore	71	N 13 W	N 77 E	11	4.0	8.0	8 37 55	8 38 5	0 10
Candor, N. C.	Hight	73	N 40 E	....	2.5	0.5	2.5	8 24 15	8 25 10	0 55
Santuc, S. C.	Jeter	75	N 11 E	N 100 E	....	....	....	8 10 48	....	....
Wake Forest, N. C.	Lanneau	77	N 32 W	....	....	....	....	....	....	....
Louisburg, N. C.	Wilder	88	N 0 W	E	....	....	....	....	8 51 10	....
Rock Hill, S. C.	Culp	97	N 36 E	NW	....	1.5	1.5	....	....	....
Mount Willing, Ala.	Garrett	98	N 11 E	E by S	5	1.0	3.0	8 38 27	8 38 34	0 7
Albemarle, N. C.	Dry	100	N 40 E	SW	Rapid	1.5	1.5	....	....	....
Elberton, Ga.	Roebuck	100	N 60 E	S 30 E	6	3.0	4.0	8 47 40	8 47 45	0 5
Senoia, Ga.	McCray	110	N 45 W	NE	....	....	....	....	....	....
SOUTH										
Rockingham, N. C.	Stansill	17	....	....	6	0.5	0.5	8 46 15	8 46 30	0 15
Little Mountain, S.C.	Glenn	25	N 50 W	NE	....	0.5	0.5	....	....	....
Hobgood, N. C.	Parker	30	....	....	....	....	....	....	....	....
Bay St. Louis, Miss.	Br. Isidore	36	....	NE	....	1.5	1.5	....	....	....
Selma, N. C.	Noble	42	N 65 W	NE	....	....	....	8 49 30	....	....
Wilson, N. C.	Hutchinson	44	N 80 W	....	10	1.0	4.0	8 50 25	8 50 27	0 2
Cheraw, S. C.	Loughlin	58	N 86 W	....	7	0.5	3.0	8 46 0	8 46 8	0 8
Biloxi, Miss.	Lemon	64	....	S	....	0.3	2.0	....	....	0 15
Belcross, N. C.	Godfrey	80	N 5 E	....	3	1.0	1.0	8 56 10	8 56 35	0 25
Batesburg, S. C.	Hite	95	NE	SE	6	0.5	1.0	....	....	....
Means		....	....	....	6.3	1.21	2.24	....	....	14.4

During this eclipse in the United States the shadow bands had a very indistinct appearance, much less prominent and marked than that which they have been described to possess at several other eclipses. The duration was very short, the bands and spaces small and flickering, and there was evidently much uncertainty in assigning to them the direction of motion, whether to the northeast or to the southwest. Before totality 18 observers gave a direction of northeast, and 3 of southwest; after totality 16 made it northeast, and 7 made it southwest. We may conclude that the motion was in reality about northeast before and after the totality, and that the uncertainty arose from the deception which the shimmering light exerted upon the observers. A similar case occurs when there is a motion of two sets of bars making an angle with each other, but wherein the bars in each set are parallel to one another. If these groups are moved by each other, it is not always easy to assign the direction of the apparent motion of the resultant optical effect.

It will be seen by an examination of the weather maps of May 27 and 28 that an area of high pressure was central over the South Atlantic and East Gulf States, which produced generally fair and clear weather in the eclipse districts. To the northward, in the Ohio Valley and New England, there was a rainy condition, though the pressure was comparatively high in all districts east of the Mississippi River. These conditions favored a very quiet state of the atmosphere in the Atlantic and Gulf States, with steady vertical gradients for the pressure, temperature, and vapor tension. I presume that this was the chief cause why the bands appeared to be small, and that if the circulation of the atmosphere had been more vigorous and congested the bands would have been larger—as much as 6 or 8 inches in breadth—such as have been observed on other occasions. This quiescent state of the air favored the formation of small bands, on the supposition that they are in part at least to be referred to the wavy and undulating currents moving in the upper strata. If these are of small dimensions the effect will be small waves, but if they are large then the bands will come down wider. When the full sun shines through these upper wavy strata its light is so powerful as to overcome any small variations that these waves could produce by the absorption or irregular refraction; but when the light is reduced to a thin crescent, then local atmospheric absorption may be of distinct importance in determining the amount that is finally received at the earth's surface. Furthermore, under the circumstances existing on May 28, it is inferred that two principal air currents were moving over the Gulf States, since the lower strata were moving northward, as controlled by the anticyclonic pressure, and the upper strata directly eastward, under the influence of the undisturbed circulation of the general atmosphere such as is described in the International Cloud Report of 1899. These two currents, making an angle of about 90 degrees with each other, would suggest that two principal sets of waves or ripples must have existed in the atmosphere, of small dimensions in general, but so disposed as to cause the effect of a shimmering and unsteady motion upon the rays of light which were observed through this medium.

DIAGRAMS OF THE DIRECTION OF THE SHADOW BANDS AND THE DIRECTION OF MOTION.

In order to exhibit more distinctly the facts contained in the fourth and fifth columns of Tables 11 and 12, regarding the direction of the shadow bands and their motion before and after totality, these data have been transferred to Charts 13 and 14. The outer circle of Chart 13 represents the section of the umbra which passed over the Gulf and South Atlantic States, and which was about 50 miles in diameter. The double line separates the diagram into two parts at right angles to the line that represents the direction of the motion of the shadow, which itself makes an angle of about 60° with the north and south line. The preceding portion of the diagram is devoted to the data for the bands before totality, and the following to those after totality. The relative distance of the several stations at right angles to the path was measured approximately on a large map, and each station was located on the circle at the appropriate place both before and after the totality. The duration, being determined by the length of the chord and its distance from the central diameter, is indicated by the position of the station. The position of the bars and the arrows shows the observed places of the shadow bands and their direction of motion, respectively. The same remarks apply to Chart 14, which merely locates the bands geographically, instead of collecting them as if seen simultaneously at one time.

The following remarks seem to be justified by the aspect of these charts. A large majority of the stations agree in assigning one direction to the general motion, namely, northeastward, instead of two directions, that is opposite after totality to that before the totality. The apparent opposite motions reported by several observers must have been due to an error of judgment caused by the shimmering motion of the bands. This general direction is found to be N. 42° E. before and N. 59° E. after totality, when the directions are all corrected to read northeastward. There is a difference of 17° between these two directions. The bands themselves lay generally in a northwesterly direction, and taking the directions exactly as they stand in the table the mean direction is N. 50° W. before and N. 22° W. after the totality. The difference is 28° and the direction of azimuth rotation is the same, that is eastward, as in the variation of the mean directions. Allowing more weight to the result for the direction of the bands than to that for the direction of motion, because more specific attention was paid during the eclipse to that special observation, we may conclude that the bands and the motion veered about 20° or 25° from the time before to the time after totality.

The direction of the shadow bands, and the direction of motion, before and after totality, as if observed simultaneously.

CHART 18.

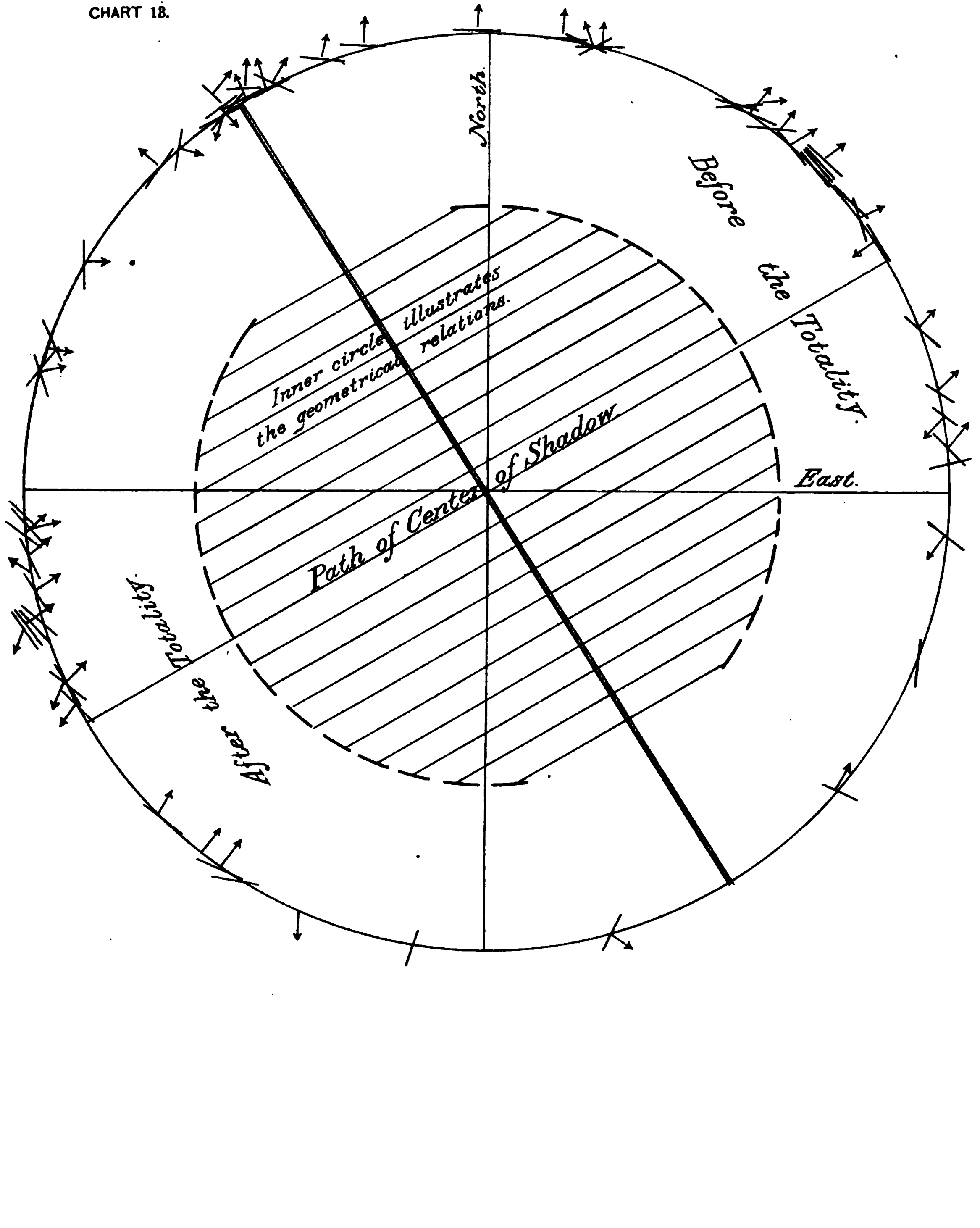

North.
Before the Totality.
East.
Inner circle illustrates the geometrical relations.
Path of Center of Shadow.
After the Totality.

CHART 14.

The same plotted geographically.

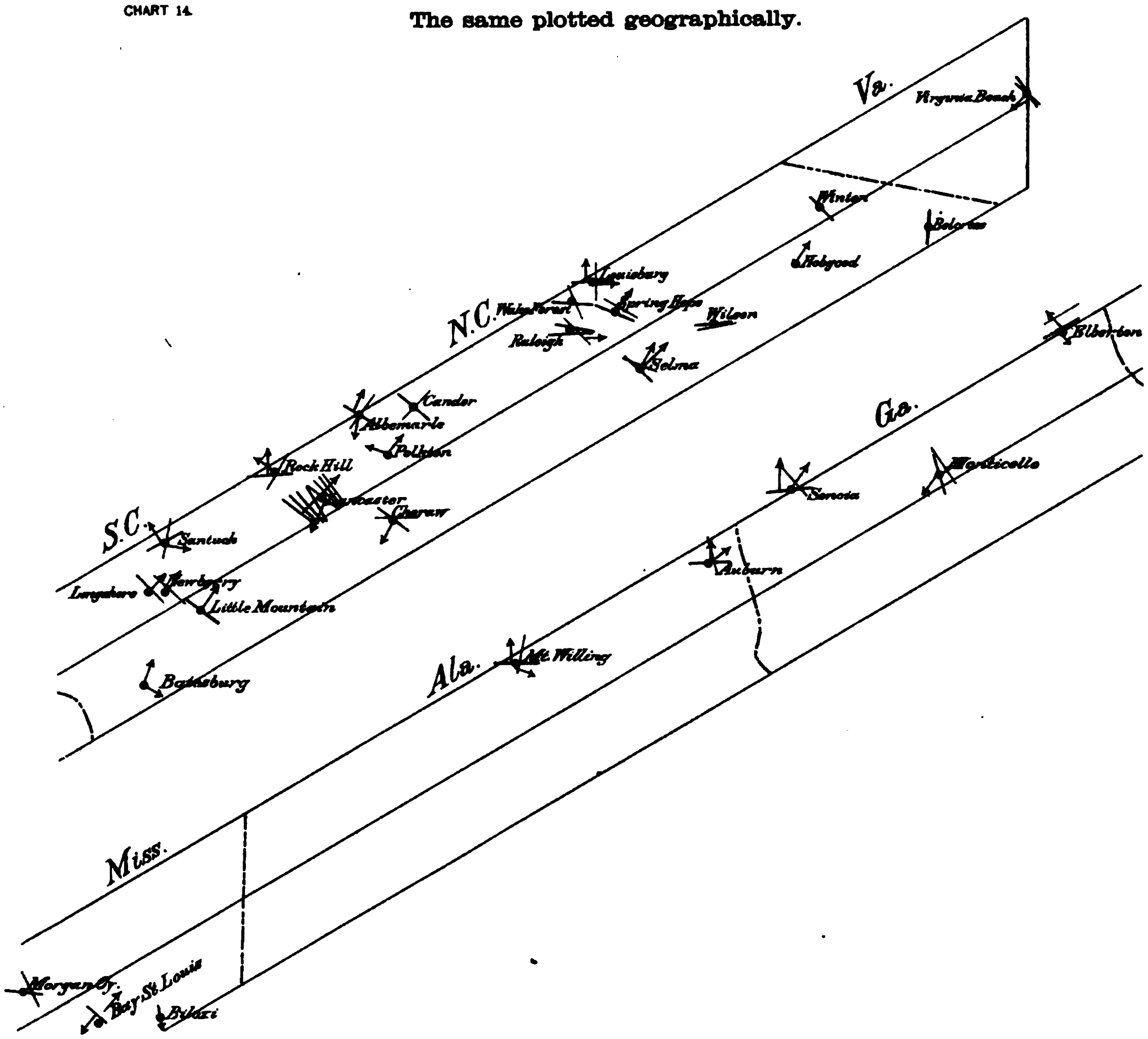
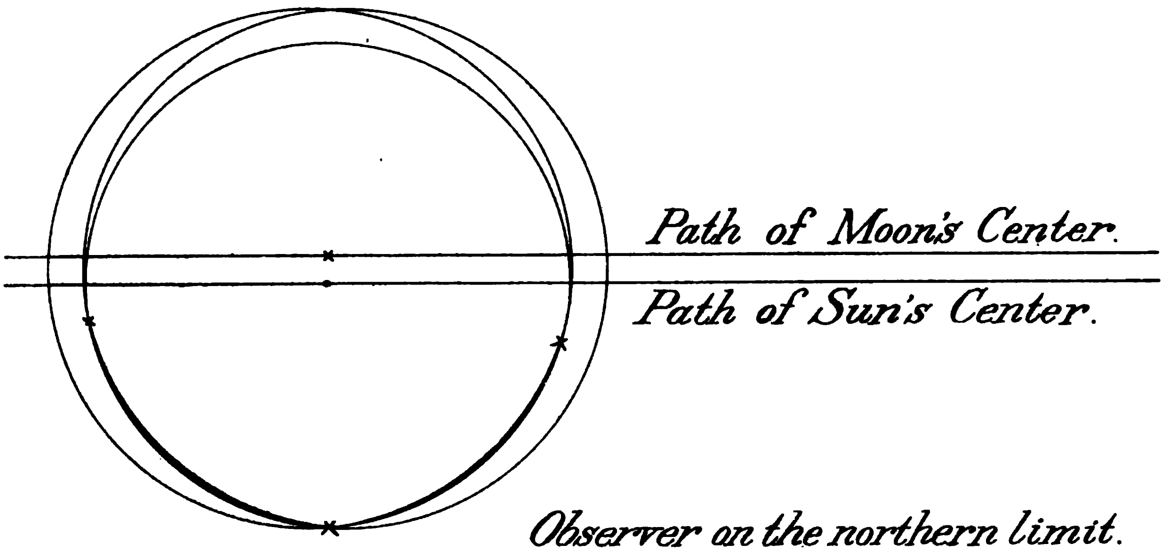
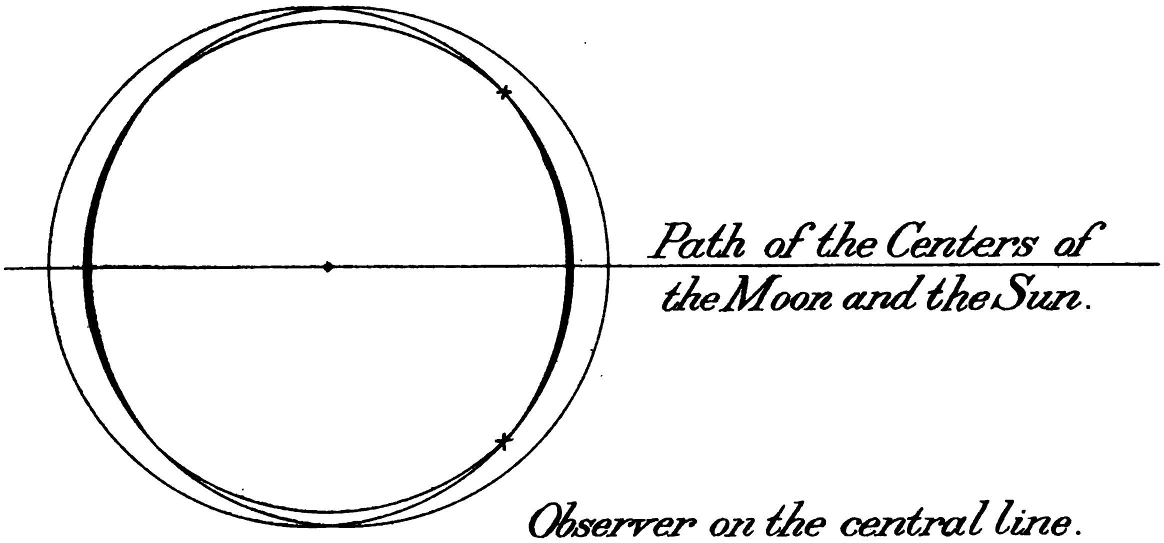


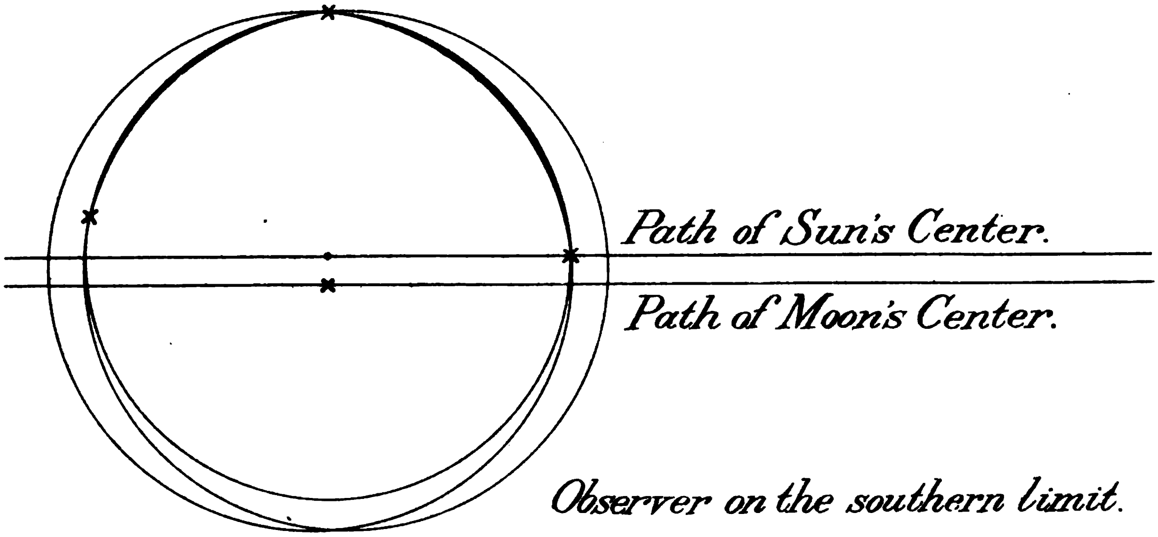
CHART 15. **Diagram illustrating the formation of the angles of the crescents.**



Observer on the northern limit.



Observer on the central line.



Observer on the southern limit.

Now, it must be remembered that according to the theory suggested above for the origin of the bands, namely, the images of the solar crescent seen through a congested semiobscure medium around the edge of the umbra, the object was not the same before as after totality, since two crescents, the first disappearing and the second appearing, are concerned. From the astronomical data of the eclipse it is found that these make an angle of several degrees with each other, varying of course with the distance of the observer from the central line. This can be verified experimentally by passing two disks of the proper dimensions over each other in positions corresponding to those occupied by observers occupying stations located first in the center, and then at greater distances northward and southward to the limits of the shadow. Compare Chart 15, illustrating the formation of the angles of the crescents.

Since the majority of our stations lay to the north of the central line, we should have a mean angle of several degrees depending upon this average distance. Specific results can not be given unless by an extensive geometrical computation involving the station coordinates.

THE ANGLES FORMED BY THE CUSPS OF THE SUN WITH THE PATH OF THE MOON, AS SEEN FROM DIFFERENT POINTS IN THE PATH OF THE TOTALITY.

The angle which a disappearing crescent before totality, or an appearing crescent after totality, makes with the line of the motion of the center of the moon's shadow depends upon the relative position of the observer within the shadow. If he is located on the center so that the center of the sun and moon coincide, the cusps are perpendicular to the line of motion. If he is on the northern edge, the center of the moon appears south of the center of the sun, and the crescent makes an angle of about 60 degrees instead of 90 degrees with that line. If the observer is on the southern side, the angle varies from 90 degrees in the opposite direction. The diagrams on Chart 15 illustrate this fact.

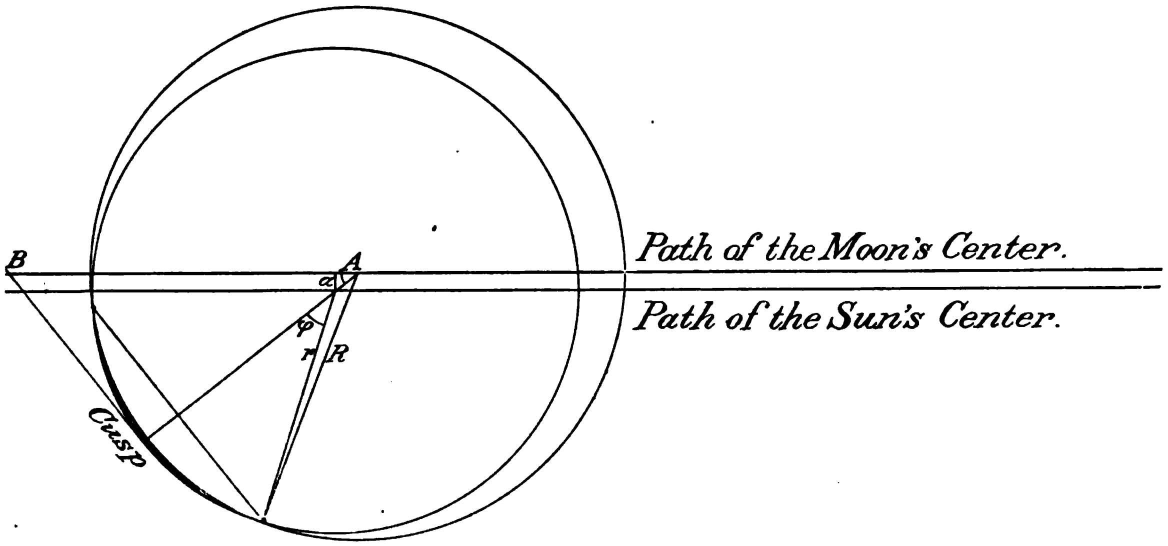


CHART 16.—Formation of a cusp with the observer to the north of the center of the path of totality.

Let r=radius of sun.

R=radius of moon.

$R-r$=radius of the path when the observer is on the northern or the southern limits.

a=the apparent distance of the observer from the center of the path.

These distances on the earth are proportional to the apparent distances on the disk of the sun.

φ=semiangle of the cusp.

A=the angle of the radius to the center of the cusp with the line of motion of the moon's center.

Then $(R-r)\cos\varphi$=the approximate distance of the centers. Hence $\sin A=\frac{a}{(R-r)\cos\varphi}$. When the arcs of the sun and moon are tangent $\varphi=0$, $\cos\varphi=1$, and $\sin A=\frac{a}{R-r}$. Since φ changes very rapidly during the last few seconds of the visibility of the cusp, therefore $\cos\varphi$ increases, $\sin A$ diminishes, so that the vanishing arc of the cusp is located closer to the central line, since the angle A is smaller. The ratio $\frac{a}{R-r}$ is the relative distance of the observer from the center of the path. By giving several values to a the position of the point of tangency on the limb is found, and thence the angle that the cusp makes with the line of motion. This treatment of the problem was suggested by remarks in a letter from Mr. Roberdeau Buchanan, of the Nautical Almanac Office.

Table 13.—*The angles of the solar cusps with the moon's path, depending on the observer's place in the shadow.*

$\frac{a}{R-r}$	A		B	
	°	′		
0.0	0	0	90	0
0.1	5	44	84	16
0.2	11	32	78	28
0.3	17	27	72	33
0.4	23	35	66	25
0.5	30	0	60	00
0.6	36	52	53	8
0.7	44	25	45	35
0.8	53	8	36	52
0.9	64	9	25	51
1.0	90	0	0	0

There has been inserted on the Chart 13 of the shadow bands an inner circle whose radius is divided into ten equal parts parallel to the diameter of motion. The chords cut the circle in points corresponding to those of the tangency of the cusps; the tangents of those points give the direction of the cusps. These can be compared with the direction of the shadow bands as observed, care being taken to compare the tangents on the small circle with the bands on the large circle which have the same proportional distances from the center. Except on the south side of the path the agreement is quite satisfactory. When one attempts to reduce such observations to geometrical angles, there is necessarily the admission to be made that the original measures of the observed angles are very rough, and that only crude results seem to be obtainable. Possibly an exhaustive collection of all shadow-band observations heretofore made in other eclipses might serve to elucidate further the view which is here proposed.

In studying the direction of the bands on the circle one receives the impression that they are more uniformly placed parallel to the same direction near the central part of the path both preceding and following, but that there is a tendency to confusion, or at least to a radical change in direction for the stations located near the edge of the path, as seen near the double dividing line, especially on the northern side, where several stations secured more and better observations. In order to bring out this fact clearly the observations are also plotted on Chart 14, where those occurring before totality are printed in black ink and those after totality in red ink. They are placed near the geographical position of the station in the path of the shadow, preserving the relative distance from the center as nearly as possible. It is noted that the black and red bands near the middle of the path are generally quite parallel to one another, but that near the edge they make a distinct angle with each other. The confused direction near the limit is due to the optical effect of the shadow cone where the interval between the two contacts is brief and the sunlight even continuous.

Thus at stations near the center of the path a distinct interval elapses between the second and the third contact, which grows shorter and disappears at the northern and the southern limits where the duration of the totality approaches zero seconds. It is evident that such stations near the center, as Virginia Beach, Va.; Spring Hope, N. C.; Raleigh, N. C.; Lancaster, S. C.; Little Mountain, S. C.; Monticello, Ga., show the two directions much more nearly parallel than do Louisburg, Candor, Albemarle, in North Carolina; Rockhill, Santuck, in South Carolina; Senoia, in Georgia; Auburn, Mount Willing, in Alabama; Morgan City, in Mississippi, all on the northern side. The data do not suffice on the southern side to discuss the point in that region. The observer at Albemarle, N. C., on the extreme northern edge, remarked:

> The shadow bands moved to the northeast before totality, and to the southwest after totality. They began to flicker across the ground just before the second contact, coming from the direction indicated, and changed rapidly around by the west to the northeast without stopping.

Here something of the change in direction was noted as a continuous motion, which might be the case if it is the images of the two separate cusps which is thrown upon the ground in close succession. The following consideration makes this clearer. The angle of the cusps with the north and south line is not the same for all observers. For stations near the central line the first and second cusps appear to make about the same angle with any given direction; for stations near the northern limit the cusps make a considerable angle with each other and are no longer parallel; for stations near the southern limit they make a similar angle, but in the opposite direction. It should be remembered that all observers do not see the same cusps on the sun, but those observed at any station depend upon the relative distances of the observer to the axis and edges of the cone. A few experiments with two disks, one a little larger than the other, will bring out this feature of the case. It seems to me that this fact of the variable angle of the observed cusps before and after the totality is clearly verified by the observations on the northern side of the path, those on the southern side being insufficient for this purpose.

FURTHER REMARKS ON THE FORMATION OF THE SHADOW BANDS.

We have thus far derived two facts to fasten the bands upon the images of the cusps as the origin of them: (1) Referred to the north and the south line, the direction of the cusps and the shadow bands are generally parallel to each other, and (2) this direction varies distinctly between the center of the path and the edge, yet keeping up the same parallelism during the local change between the cusps and the shadow bands. If these two geometrical facts are the correct result of this analysis of the observations, they are practically decisive in regard to the origin of the bands. Referring again to Tables 11 and 12, it is seen that the mean velocity of motion of the bands before totality was 6.6 feet per second, and after totality it was 6.3 feet per second, the average being 6.45 feet per second. This is a surprisingly small velocity from every point of view. Some observers even hinted that in their opinion the flickering motion did not seem to move forward with any assignable velocity, but was more like a forward and backward motion. Prof. J. T. Coleman, of the South Carolina Military Academy, Charleston, S. C., who had made elaborate preparations with several assistants to record all the features of the phenomenon, stated in his report:

> The point which was uppermost in our minds was that the bands would move forward with a definite speed. When they appeared, some of the students lost much time in deciding what they should do. The student with the stop watch could not decide that he should run at all, nor did he do so either before or after totality; neither did anyone whose duty it had been made to do so.

Mr. Greenleaf W. Pickard stated:

> Some little difficulty was experienced in determining in just what direction the bands were moving; that is to say, whether southwest or northeast.

The observers generally agreed that the motion was either slow or else indecisive in direction. Now, all this is quite positive against the diffraction theory of the origin of the shadow bands. The umbra on that view is surrounded by a fringe of diffraction bands disposed in circles around its center and necessarily borne along at the same speed as the shadow of the moon, since the diffraction phenomenon must be due, if it exists, to secondary waves formed at the edge of the moon, according to the usual physical principles. The shadow moved from New Orleans, La., to Norfolk, Va., about 1,000 miles, in 25 minutes Greenwich mean time, so that the rate is 40 miles per minute, or 2,400 miles per hour, which is equal to 3,500 feet per second. If they had any such velocities, the diffraction bands could by no means be detected by our observers, and certainly they would not be recorded as having velocities of only 6 feet per second, with a flickering unsteady motion. Furthermore, the diffraction bands must, if they exist, consist of colored or spectrum fringes, but nothing of this kind has ever been detected. We therefore dismiss the diffraction theory from further consideration.

The columns of Tables 11 and 12, giving the times of the beginning and ending of the visibility of the bands, are less satisfactory than could have been desired, owing to the difficulty of observing so brief a phenomenon. After excluding a few results, as shown by brackets, the mean is a duration of 12.3 seconds before and 14.4 seconds after totality, being an average of 13.3 seconds. Since the duration of the total eclipse for the stations varied from about 90 seconds near the center to 0 second at the edges, we may take 60 seconds as a fair integral mean. Hence the duration of the visibility of the bands is about one-fifth that of the entire shadow. The shadow is nearly 50 miles in diameter, so that the medium which is favorable to the production of the shadow is one-fifth of 50 miles; that is, about 10 miles in thickness. We are, therefore, brought to conceive of the umbra as surrounded by semiopaque rings in the plane sections, perpendicular to the axis, of such a character that the crescents of the sun's disk will cast down images upon the ground through a flickering and wavy medium. The width of the bands was found to be on the average 1.37 inches before totality and 1.21 inches after totality; the bright spaces were 2.15 inches before and 2.24 inches after totality; the mean for the bands is 1.30 inches and for the bright spaces 2.20 inches; the total width from a given point on one band to the same point on the next band was 3.50 inches, and the ratio between the width of the bands and the bright spaces is 1 to 1.7; on a scale of 100 the ratio is 37 to 63. It must be admitted that there is some uncertainty, if not difficulty, in describing the exact action in the atmosphere close around the umbra shadow which should cause its edge to be surrounded by a semiopaque medium such as we have likened to the leaves of a tree.

A similar physical phenomenon is, however, well known. Thus, in Lehrbuch der Meteorologie von Dr. JULIUS HANN, 1901, page 17, the obscuring of the atmosphere by minor convection currents is described at length. In Astrophysics, February, 1897, page 107, on the "Effect of pressure in the surrounding gas on the temperature of the crater of an electric arc," by W. E. WILSON and G. F. FITZGERALD, it is said:

> We would, in conclusion, call attention to a cause of opacity in the solar atmosphere that is illustrated by the effect of convection currents in the long tube we were observing at high pressures. These convection currents behaved just like snow, or any other finely divided transparent body immersed in another of different refractive index. Light trying to get through it is reflected backward and forward in every direction, until most of it gets back by the way it came. The consequence was, that even the electric arc light was unable to penetrate the tube at high pressure when the convective currents were active.

Several facts have been developed that may have more or less influence in supporting this view of the origin of the shadow bands: (1) The thin crescent which is the condition of the bands appearing has so small an amount of penetrating light that any source of absorption is more efficient than in the case of ordinary full sunlight. The minute waves in the atmosphere existing under ordinary circumstances when currents are moving, and which become conspicuous under some types of cloud formation, may properly be referred to as disposing the aqueous vapor near the shadow to condense into minute cloudlets between which the images are propagated. (2) The effect of the shadow cone itself is to thrust a cool medium into one of higher temperature, as an icicle into a mass of water, so that the immediate effect is to cause circular heat waves to be set up with convection currents directed radially toward the center of the shadow. This disturbance may be felt generally to considerable distances, and one-fifth of the diameter of a cone does not appear to be an excessive distance to assign to such temperature exchanges. (3) There are certain irregularities on the moon's edge, and also there are others on the sun's disk, as shown by the light of the inner corona. If the disk of the sun were bounded by an absolutely sharp edge as a source of light, we should see a cone formed with a more nearly geometrical shadow and sharp surface at the earth. But the breadth of the inner coronal ring may play a certain part in causing the light of the sun to surround the moon's shadow with a fringe of irregular light, which would have a tendency to throw down the crescent of the true disk as an irregular shadow on the earth, as seen from the edges of the shadow itself. From these three causes we may expect to observe that the umbra changes into the penumbra by means of a turbulent ring or obscuring medium partaking in character of each of them during the time of the transition. From the foregoing we conclude that although the bands are more readily observed, yet it is the light spaces which correspond to the solar crescents and the bands to the obscure parts of the medium. This distribution evidently admits that only one-third of the medium of the ring is in an opaque condition, the rest being illuminated by the shimmering light of the solar crescent.

CHAPTER 4.

SOME RELATIONS BETWEEN SOLAR AND TERRESTRIAL PHYSICS.

GENERAL REMARKS ON THE SOLAR CORONA.

The physical nature of the solar corona continues to be a puzzle to astronomers, and theories regarding it have been proposed from nearly every possible point of view. The corona consists of two portions, the inner and the outer, the former being thin, near the sun's disk and complex in its constitution, the latter extended and consisting of very tenuous materials. Part of the coronal light is polarized and is reflected, being derived from other sources than the coronal material itself; part of the light originates in the coronal material, which is, therefore, incandescent, this being the case especially near the sun. This coronal substance seems to be fine dust, or else the debris of disrupted molecules and atoms, either derived from ejections of the sun or from meteoric sources. It is not a simple gaseous atmosphere like that of the earth. The sun must possess a definite quasi-permanent structure, which may be described as follows, according to the latest ideas on the subject.

There is a nucleus of unknown diameter, probably having some such relation to the visible surface as the earth to its cloud layers. From this nucleus rise streams of cooling material in vertical directions that terminate in a layer called the photosphere, which is the apparent visible surface of the sun. These uprising columns condense at a given average distance, but the irregularities in the upward motions give rise to certain characteristic features, namely, the granulation of the surface, the faculæ which exist in all latitudes as large diffuse streaks, but chiefly occur in the sun-spot belts, the sun spots, located in zones within 35° of the equator, undergoing periodic changes in relative number and in latitude; the prominences, quiescent or irruptive, fiery, cloud-like forms projected above the sun's visible disk, in extreme cases as high as 300,000 miles, most frequent in the sun-spot belts, but falling off to latitude 65° and increasing again somewhat in numbers about the poles. Just above the average position of the photosphere lies YOUNG's reversing layer, which contains within a thousand miles of thickness the materials that give forth the bright lines corresponding to the dark lines of the spectrum. Lying upon this reversing layer is the chromosphere, a gaseous envelope 5,000 to 10,000 miles thick, composed mainly of glowing hydrogen, with a few other metallic substances, through which the prominences are ejected; finally, the tenuous and very extended coronal appendage already mentioned. This complicated structure is now studied with increasing interest, and the difficulty of satisfactorily understanding the conflicting facts of solar physics but adds zest to the research.

The view just described is the old well-known condensation theory of the sun, which has been in vogue since the days of WILSON and HERSCHEL. On the whole, it may be said that it seems to require modification to some extent under recent modern research, and the belief is growing that it must be largely supplemented in order to account for all the facts. It is noted that this old theory deals only with the cooling and condensation of material passing up and down vertically from and toward the center of the sun, and it appeals only to the laws of thermodynamics. On the other hand, it is being widely recognized that under the conditions of enormous temperatures which prevail on the sun there must occur such processes as the dissociation of molecules into atoms, and also of the elemental atoms into more primitive subatoms. The laws of circular refraction exhibit evidences of operation, and the forces of electricity and magnetism also seem to play an important part in the physics of the sun. From all sides comes testimony regarding two facts: first, that the sun has a quasi nucleus and an apparent disk separate from it; and second, that these have a more or less permanent mechanical structure. This is a conception entirely different from the old notion of the sun as a vast structureless mass of incandescent vapor. The pressure of gravity in the sun would make ordinary gases have a stiffness like tar or pitch, and the metallic vapors near the center of the sun may well be so highly viscous as to be nearly rigid. This structure must be quite stable, because the periodic changes upon the sun's surface while going through well-defined variations are now known to be repeating themselves in a cycle embracing not only the solar substances, but also the magnetic and electric fields of the earth and the meteorological conditions that make up the weather. There was a time when hydrogen was supposed to be the lightest gas, but we now have a lighter one, helium, which occurs in the lower layers of the corona, in the earth, meteorites, nebulæ, and stars; there is coronium, having a green line in the spectrum of the corona, but not yet detected elsewhere, and apparently occupying a stratum up to about one-fourth the sun's radius above the disk; also there is ætherion, described by **Brush**, one-thousandth part as heavy as hydrogen, and it must have atoms so much smaller than hydrogen and a molecular velocity so much greater that it streams through glass and mercury as hydrogen does through potter's clay; finally, there is probably a "radiant matter" which pours forth from the sun millions of miles along the equatorial coronal rays, so delicate as to be hardly distinct from the ultimate æther of interplanetary spaces and comparable only to the ionized products of discharge vacuum tubes. With all these new forms of matter and the application of electric and magnectic forces to consider, much that was readily credited twenty years ago comes up for revision. The old argument was long accepted that because a comet's motion is not sensibly retarded on passing very close to the sun's surface there can be no material substances in that region, and that therefore there is a sudden transition from a sphere composed of true material substances immediately into a vacuum. It has been shown, however, that a comet's head may pass through a real gas under certain conditions without sensible retardation, because the friction merely strips off a thin surface shell without disturbing the motion of the nucleus; and also that such relations can exist between the mechanical velocities of motion and the wave lengths of the propagation of energy, depending on the state of the gas, as to enable a body to pass through it (the gas) rapidly without retardation. It is probable that we must abandon the comet argument for a vacuum near the sun.*

There are three other theories which may be mentioned on account of their interest and importance in the attempt to account for certain difficulties of solar physics. These are the ballistic theory, the dissociation theory, and the circular refraction theory, respectively. If the sun were simply a vaporous globe it is impossible that the disk should be as sharply defined in a circle as we observe it to be. The fine line of the sun's disk, together with the superposition of the coronal appendage, contradict each other in some respects and constitute a very hard problem to resolve.

It is sought to explain the protuberances as masses of incandescent material ejected from below the photosphere into the vacuum which is assumed to surround the sun, terminating sharply on the apparent disk. This view implies that there is no gradual diminution in the density of the sun's layers from the nucleus outward, as in the earth's atmosphere, but that at a fixed distance above it, at the photosphere and chromosphere, there is an abrupt discontinuity into a vacuum. The difficulties with this view are that such discontinuities are very seldom found in unconfined vapors and gases, but in them there is a gradual diminution to the limit. If a large mass of hydrogen vapor having the size of the earth be thrown up from the sun's disk, the space filled up by the resulting prominence would be occupied within half an hour or less. During this time the outer layers of the prominence cool by expansion, while the core remains at about its original temperature, so that a great change takes place in density from the center to the surface of the prominence, and this should produce corresponding refractions in the light; these, however, have not been certainly observed. The great irregularities measured in the velocities that prevail during the development of a prominence do not match with those that would mark a bomb thrown up as a projectile. In the metal lines of the solar spectrum upon and within the disk velocities as great as 600 kilometers per second are observed, but in the protuberances the highest velocities are only about 40 kilometers, showing that these must have a different origin from that of the velocities of the gases within the sun, as they are there tossed about in the processes of incandescence.

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* Ein Bild des Sonnenballs, A. Schmidt, Deutsche Revue, Juli, 1899.

The dissociation theory is illustrated by taking aqueous vapor, which separates into oxygen and hydrogen gases, forming oxyhydrogen gas at a high temperature. In the same way, with greater solar heat, oxygen and hydrogen atoms may be dissociated into more primitive elements unknown upon the earth. Since the coronal extension seems to be made up of elements much lighter than hydrogen, it is supposed by some that the visible disk is that surface where the chemical dissociations and combinations are chiefly taking place. The granules, faculæ, spots, photosphere, and chromosphere are appearances attending these chemical processes. There must be much truth in this view, and something of the kind may be going on at the sun's disk, if it can properly be assumed that the known terrestrial atoms do break up still further when subjected to solar temperatures. Yet it is hard to see how such a process could produce a sharp boundary at the visible surface, having considerable densities on one side of it and great tenuity of material on the other. Furthermore, since the cooling is from within outward, we should expect to find dissociated or solar constituents inside and terrestrial combinations outside the layers having the critical temperatures, but this is the reverse of the facts. Nor could the same temperature be critical for the dissociation of several different elements. In other words, dissociation ought to take place at different levels, and thus produce a gradual shading in the density outward, instead of the sharp disk which is always seen.

The circular refraction theory starts with the phenomenon that if a sphere is surrounded by a mass of gas of densities diminishing with the height, there exists a circular layer where a ray of light from the outside falling upon it at a tangent will continue to travel around the sphere in a circle at the same distance from the center. If a golden ball one inch in diameter is covered with a shell of glass one-half an inch thick, the golden sphere will seem to be magnified to a 2-inch globe by the action of circular refraction, and the glass itself will not be seen at all. In the same way, since the nucleus of the sun is smaller than the disk, it is supposed to be optically enlarged to the visible size by such a refractive action of the spherical layers surrounding the sun upon the emerging rays of light. This theory is interesting, has several points of special value, and is receiving considerable attention. The result is that the appearances on the visible sun's disk are all supposed to belong to regions one-third the radius nearer the center, and that the changes on the sun's surface noted in the telescope are more or less optical exaggerations; in fact, only secondary appearances. We therefore perceive a sharp circular disk high up in the sun's atmosphere, whereas in reality it belongs to a nucleus far below.

An important point regarding all these theories—condensation, ballistic, dissociation, and circular refraction—is that they imply that the sun has a solid or highly viscous nucleus of definite structure, capable of slow periodic movements within itself, where the energy is transformed from one state to another; also that it is being subjected to sudden quivers or shocks as this energy spasmodically seeks to free itself from temporary constraints. Much evidence has been collected to show that the earth sensitively reflects these solar influences in synchronous impulses through the magnetic and electric changes in the state of the atmosphere. This solar-terrestrial branch of physics, it is readily seen, is not only fascinating as an object of study, but it is likely to become of great practical importance if the laws controlling the physical processes can be fully analyzed. It is with the object of reviewing the recent advances in this branch of astrophysics that I have attempted to bring together the results of our knowledge on these topics. It will be shown that the meteorologist has, scientifically, much more interest in this subject than has been commonly realized, and that a new light is being thrown upon several obscure portions of meteorology by means of these astrophysical investigations.

SCHMIDT'S CIRCULAR REFRACTION THEORY OF THE SUN'S DISK.*

SCHMIDT's theory of the sun's constitution and appearance depends upon the optical phenomenon of circular refraction. If a sphere is composed of gases stratified by their molecular or atomic weights so that the heaviest are at the center, and the density decreases outward, there is a possible proportionality between the radius and the index of refraction for a certain stratum, such that a ray of light tangent to the critical layer will undergo circular refraction and remain at the same distance from the center of the body. If a ray, by reason of a larger angle of incidence at its source, escapes above this circular layer, it will make its way into space, and its curvature is less than in circular refraction, this being the type in the terrestrial atmosphere. If the ray, by reason of a smaller angle of incidence from the inner and lower strata, fails to reach the circular refraction layer and pursues its path within gases of relatively high density, it will not escape, but will recurve toward the original layers from which it proceeded, and this case may be designated solar refraction. There are two effects produced by this action of the rays, (1) an apparent magnification of the interior strata to the size of the circular refraction layer, and (2) the production of an optically sharp boundary called the disk. This is the chief purpose proposed by the theory, namely, to account for the abrupt termination of the visible body of the sun, which is doubtless a troublesome problem. It assumes that the sun is gaseous throughout, relatively quiescent, stratified by specific gravity, and that many of the observed phenomena at the visible surface are optical effects of irregular refraction processes upon the rays of light at invisible depths. The photosphere, the spots, the reversing layer, the chromosphere, the faculæ, the prominences and the corona, with the almost infinite number of differential circumstances belonging to them as indicated by the spectroscope, the camera, and the bolometer, are really observed only indirectly and inferentially.

This theory assumes an ideal sun which does not seem to conform to the established facts, so that critical objections have been urged against it which remained unanswered. Thus, (1) the evidence does not admit that the heavy metals are located near the center of the sun, while the light elements are confined to the outer layers, for, if so, the pressure upon the heavy metals would produce a continuous or at least a banded spectrum, while many of them have very fine lines. The spectrum shows such irregularity as regards density as to make it necessary to infer that the gases themselves are thoroughly mixed. (2) While the circular refraction layer is a sharp boundary, yet this implies that above it the gases diminish gradually in density out into the coronal region; on the other hand, the facts derived from the behavior of comets, from the quiescent and irruptive prominences, seem to show that there is in reality a sudden fall in density from that prevailing in the chromosphere to the coronal rarefaction, which is nearly an absolute vacuum. SCHMIDT tries to meet the objection from the comet argument, namely, that the velocity of propagation is not retarded when a long path of its trajectory passes through the coronal regions, by maintaining that a body may move through gaseous media without hindrance for two reasons. First, the friction strips off only a thin superficial layer by heat fusion, while the nucleus proceeds unchecked; second, certain relations between the velocity of propagation and wave length of transmission of energy exist in which there is no change of the velocity of motion of a solid body through a gas. These purely physical theorems are not yet proven, however, to be applicable to the case of the sun. (3) If the rays from the interior should pursue a very long path through heavy gases before reaching the layer of circular refraction, absorption of light would so far operate as to cause practical extinction. One can not escape from this point by an appeal to selective absorption, and yet leave intact so many lines in the spectra of the elements as are found in the sun, and proven to be so preserved by direct comparison with the terrestrial elements, where selective absorption certainly can not be effective. (4) The reversing layer, which by its inverted flash spectrum reveals the approximate level where originate the rays of light propagated into space and visible at the earth, is located at the base of the chromosphere, just above the photosphere. On SCHMIDT's theory, this layer is optically elevated from great depths, and it is a compound effect of spectrum radiations generated at different distances from the center of the sun. The denial in general terms of the existence of this layer will hardly be accounted competent to offset the specific spectroscopic details which the observations at several eclipses have brought together. Furthermore, these reversing spectrum lines should appear generally broadened, but this is not the case on the photographs.

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*Die Strahlenbrechung auf der Sonne; ein geometrisches Beitrag zur Sonnenphysik, von August Schmidt, Stuttgart, 1891. Die Schmidt'sche Sonnentheorie, Otto Knopf, Jena, 1893. Schmidt's Theory of the Sun, Wilczynski, Astrophys. February, 1895. Ein Bild des Sonnenballs. A. Schmidt, Deutsche Revue, July, 1899.

ANOMALOUS DISPERSION IN THE SUN'S ATMOSPHERE.

The path which rays of a given wave length traverse in an atmosphere depends upon the density and the refractive index of its successive layers. If it is homogeneous in density, the path of the ray is a simple straight line; if the density varies by a law regularly from the bottom to the top, as in the earth's atmosphere, the path is a curve of definite form; if the density is irregularly arranged, as in prismatic masses, then anomalous refraction occurs. In this case the spectrum lines may be seriously transposed from their natural arrangement and placed in a different order, even to changing the color succession usually observed. Hence, in the atmosphere of the sun, if the metallic vapors are congested in spherical or prismatical masses, instead of lying in simple horizontal strata whose density decreases from the center of the sun outward, the conditions are present for anomalous dispersion of the solar spectrum. Then the rays of the photosphere coming through the chromosphere will show a distortion corresponding to the density of the layers of the higher atmosphere through which they pass, and an observer at the earth will perceive these anomalous forms and positions in the spectrum lines.

It is known that the index of refraction varies rapidly on each side of the line of a given wave length. Thus, if the sodium D_1 D_2 lines have a given index of refraction, for wave lengths slightly greater than λD_1 λD_2 the index of refraction increases rapidly in the immediate neighborhood of the absorption line; for waves slightly smaller it decreases rapidly. Therefore the rays coming from different depths in the sun's atmosphere may be so refracted as to be practically superposed, even if not belonging to the same substance. An absorbing line of the upper atmosphere may seem to have very nearly the same position as an emitting line of the lower atmosphere, though physically independent of one another. Hence bright photosphere lines may seem to have the same places in the spectrum as the ordinary dark lines which are due to real absorptions in the chromosphere. Many apparent chromosphere lines may be in reality photosphere light refracted by anomalous dispersion. Rapid changes in the distribution of density will cause broadening of the spectral lines, irregular forms, offshoots, reversals, and even double reversals. These are the features commonly seen in the sun spots, the reversing layer, the prominences, and the chromosphere. These rapid changes in the visual spectral lines have been generally attributed to DOPPLER's principle of motion in the line of sight, but excessive linear velocities have been required to account for the observed displacements. Anomalous dispersion is equally capable of producing the variations noted in the form, length, and position of the spectrum lines, and it is very probable that both of these principles are in fact operating in the sun's atmosphere, thus relieving the DOPPLER principle of its too heavy burden. Thus, part of the spectrum may actually arise from emission in the chromosphere, and another part by anomalous refraction from the photosphere to make up the known chromosphere lines.

These phenomena have been reprodued in laboratory experiments by W. H. JULIUS,* R. W. WOOD,† and H. EBERT;‡ also in part by H. BEQUEREL.§ These experimenters imitate the flash spectrum of the reversing layer, many of the characterics of the sun-spot spectra, and the leading features of the prominences, by simply passing the light of a continuous spectrum through layers of a gas varying rapidly in its density and having a form approximately prismatic in outline. The wave lengths which are very close on either side of those of an emission line, though actually coming from a different substance, are the ones causing this phenomena by the action of anomalous refraction, and therefore many things which have hitherto been attributed to motion in the line of sight must receive a new critical examination. The subject of refraction in the solar atmosphere will probably merit an increasing amount of attention in the future for the reasons indicated.

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* Astrophys., October, 1900.

† Astrophys., January, 1901.

‡ Astron. Nachrichten., Mai 1901, No. 3708.

§ Compt. Rend., 127, p. 899, 1898; 128, p. 145, 1899.

THE CONDENSATION AND DISSOCIATION THEORY.

The common view regarding the formation of the disk of the sun is that it is generally a region characterized by abrupt changes in its constitution, a locus of physical condensation of metallic vapors to saturation under the conditions of pressure, temperature, and vapor tension prevailing at that level of the sun, the analogous problem on the earth being the formation of clouds of aqueous vapor; also it is a region of chemical dissociation and recombination of the elements. Specimen papers on this subject may be found in Anwendung der Mechanischen Warmetheorie auf Kosmologische Probleme, A. RITTER, 1882; Mathematical Spectral Analysis, R. von KOVESLIGETHY, A. N. No. 2805; The Remarkable Relation between the Spectrum of Aqueous Vapor and the Line Spectrum of Hydrogen and Oxygen, as well as the Chemical Structure of the Two Last and Their Dissociation in the Sun's Atmosphere, A. GRUNWALD, A. N. No. 2797; On Solar Physics, J. F. HERMANN SCHULTZ, A. N. No. 2817. These papers all make the sun to consist essentially of a nucleus of some sort surrounded by a layer of special chemical activity at a considerable distance above it, the total mass of the material of this structure being equivalent to that computed by astronomical laws. Another modification of the last view is that the isolated superficial layer is the seat of intense electrical currents and discharges, causing dissociation of the molecular material and emitting streams of radiant matter into the coronal regions. At the same time the nucleus is the seat of intense magnetization, and the field of magnetic force depending upon it influences the visible aspect and curvature of the coronal extensions. This is the view which has for many years seemed most probable to me, and it is the one toward which I have devoted my efforts with the object of gaining definite evidence in its favor. Before returning to its discussion it will be desirable to continue our review of the recent theories of the sun in order that all the important facts may be before us previous to drawing our final deductions. At present it is proper to state that, in the opinion of most astrophysicists, SCHMIDT does not seem to have satisfactorily made his theory of the sun include many indisputable facts, and that in consequence of this failure the theory of the simple gaseous structure of the sun, which has satisfied some astronomers, has met with a serious reverse. If the gaseous constitution of the sun breaks down in its most elementary form, it is next in order to try the hypothesis of a viscous nucleus surrounded by a more or less distant concentric spherical shell, the seat of condensations, of chemical dissociation and recombination, of electrical currents and electrostatic forces, of atomic radiant energy, while at the same time the nucleus is the seat of a magnetic field of force.

THE PHOTOSPHERE AND SOLAR SPOTS.

The problems of the relation of the solar spots to the photosphere, and the cause of the darkness of the spots, instead of being satisfactorily explained as a result of the evidence derived from observations of various kinds, seem on the other hand to have become even more bewildering than they were some years ago. This no doubt in part is due to the fact that the phenomena are more complex than was supposed, and that more is now known about the details involved which must be explained along with the account of the general theory. Furthermore, the results of the observations are very contradictory; this may be explained, at least in part, by supposing that the sun spots do not rigidly conform to a single type, but really exist under different physical aspects sufficiently divergent from each other to afford inconsistent evidence, unless this is classified with regard to more special subdivisions in the general point of view.

The facts made known by different observers which seek for reconciliation in the scientific explanation of the processes in the sun, signalized in the spot phenomena, may be summarized as follows: The spots undergo decided variations in their relative frequency in the so-called eleven-year period, which, however, fluctuates considerably about the mean duration of the cycle in intensity or amplitude. The spots at the beginning of the minimum of the period form in four belts, two each side of the solar equator, one of these in either hemisphere near the upper limit in latitude, which is about 35°, the others quite near the equator. The belts nearer the poles consist of a fresh irruption of spots, while those close to the equator are the remnants of the period which is passing off, since in the eleven-year period the mean spot belts gradually descend from higher latitudes, approach the equator, and there disappear. Hence at the maximum of the period the spots occupy the middle zones near latitude 14°. The drift in longitude is greatest at the equator, where the period of rotation of the solar surface is 24.86 sidereal days. Toward the poles this gradually reduces to about 27.50 days in latitude 45°. It is not known with certainty what the angular velocity is at the poles of the sun, but it is probably the same as at the equator, so that the velocity of middle latitudes indicates an antirotational draft, being slower than at the equator and poles. The spots themselves appear to consist of masses of metallic vapors and gases which are cooler than the surrounding photosphere and strongly absorb the solar radiation. The majority of the observations indicate that they are true depressions in the photosphere, the curvature being concave downward; other observations on the contrary seem to show that they are elevations above the photosphere and have their surfaces of equal density convex upward. De la Rue, Loewy, Stewart, Secchi, Ricco, and many others confirm the Wilsonian or depression theory; Howlett, Spoerer, Perry, Ranyard, Whipple, Sidgreaves, and others maintain the elevation theory. Besides these contradictions from direct visual observations, we have equally divergent testimony from the spectroscopic results of measures on the width and position of the spectral lines. The same lines which are seen in the photosphere usually run across the spectrum of the penumbra and the umbra of the spot. Some of these lines are widened in the umbra and undisturbed in the penumbra; some are widened in the penumbra but are not modified in the umbra; others are reversed throughout both portions of the spot; the majority of lines, however, are the same in the photosphere and also in the spots. These changes may arise from relative motions in the line of sight, from local variations in the pressure and the temperature, from absorption in superposed layers, and from the action of a magnetic field upon the electrically ionized charges whose oscillations are supposed to emit and cause the spectral radiation. The only conclusion to be drawn is that a sun spot is the locus of extremely active operations of many chemical and physical forces, and that these processes indicate an especially complex and turbulent field of action.

More positive testimony as to the relative elevation of the sun spots is given by the results of observations by Stratonoff, Belopolsky, Wolfer, and some others, who affirm that the order of relative angular velocity in longitude increases upward, that of the spots being greater than the photosphere and less than the faculæ, so that the order of elevation is photosphere, spots, and then faculæ. Passing over the rather natural surprise one feels at supposing the spots to drift over the photosphere—like clouds over the underlying regions of the earth—because they are floating in a stratum having a different relative velocity of motion, it may be remarked that the fact, if accepted, of greater velocity of the spots may not necessarily be interpreted as pertaining to a higher elevation. If the solar spots have any analogue in terrestrial meteorology, it is in the cyclones which drift about within their proper stratum, through the action of the local currents that generate them. We should need assurance that no horizontal currents exist at the level of the photosphere, and this is not likely to be true, before the above conclusion is accepted as a necessary inference. Wilsing and others state as the result of their observations, moreover, that the spots and the photosphere do not have a different rotational drift in longitude. Again, Langley, Frost, and Wilson find that while the thermal radiation from the center of the sun's disk decreases by a certain law to the limb in consequence of the absorption in the thicker layers through which the rays pass at the limb, yet the thermal radiation from the spots does not diminish quite so rapidly as that of the photosphere. This could be explained by an elevation of the entire spot above the photosphere, or else by a partial elevation of the upper portion of the spot over the level of the photosphere, such as Hale has suggested. Also some spots seem to radiate more vigorously than the adjacent photosphere, and from this it is inferred that there is less absorbing material lying above them, and that, therefore, they must be somewhat elevated. Finally, Cortie states that certain umbra have been seen on the limb of the sun to pass off at a distinctly higher elevation than the photosphere itself. Allowing for the difficulties of this contradictory evidence, we are inclined to conclude that some spots form so that their upper portions are higher than the photosphere, but that their lower parts are always buried within the photosphere itself, and we shall endeavor to show how this may occur in harmony with the facts. Spots do not, however, always conform to this criterion, but some may be so constructed that their upper parts shall be substantially on a level with, and some spots even below that of the surrounding photosphere.

There are a few more minor features to be mentioned regarding the phenomena of spots. It has been repeatedly observed that visible masses float toward a spot center from all directions, and apparently precipitate themselves from above into the midst of the spot. The faculæ occur commonly in a sort of rough hedge around the border of the penumbra; they also float at higher levels directly over the spot, like cirrus clouds over the underlying cumulus of a terrestrial cyclonic area. Spoerer finds that currents sometimes converge toward a certain spotless region, and that soon thereafter a spot forms at the place of convergence. The spot structure presents a typical well-defined formation, with radial light and dark rifts over the entire photosphere. There is little if any evidence of tangential circulation within the spot itself, though an entire spot may rotate slowly about a vertical axis. The material of the spot is very quiet on a large scale as compared with molecular and other minute motions; a multitude of fine lines have been found by Young and others well within the umbra, which indicate rapid chemical combination and dissociation.

THEORIES OF THE FORMATION OF SOLAR SPOTS—FAYE'S, VON OPPOLZER'S, AND SECCHI'S THEORIES.

There are three general theories concerning the formation of sun spots which have received attention, namely, Faye's, Von Oppolzer's, and Secchi's. Faye used the meteorological analogue of the terrestrial cyclone, Von Oppolzer the anticyclone, and Secchi, as it were, a combination of these two types. Faye would generate the cyclone, with its ascending vertical circulation, by means of the differential relative angular velocity of the drift in the photosphere, which produces the right and left handed gyration, respectively, in the north and south hemisphere. This theory has never satisfactorily answered the criticisms that gyration is so rarely observed in the solar spots that it can not be an essential feature of them; that the differential velocity in the photosphere is much too small to produce cyclonic action; and that in ascending currents the upper portion is relatively colder than the bottom, while the absorption in sun spots requires this relation to be inverted, so that the layers in spots shall be colder below and warmer above.

Von Oppolzer appeals to anticyclonic phenomena in the earth's atmosphere for an analogue to the sun spots, especially to the descending current in the winter, which is characterized by an atmosphere cleared of visible aqueous vapor, through which the dark earth is visible to an outside observer, and to the strong inversion of temperature which makes the lower strata colder than the upper. He seems to think that a descending current of solar vapors where the increase of temperature is as much as 6,000° C. in 11.4 miles, or 1′ of arc, could yet maintain what was condensed in the upper layers in a state of cloudiness. This rate of adiabatic temperature change leads to impossible temperatures in the interior regions of the sun, especially in view of the fact that the latest investigations on the effective temperature of the sun's radiation makes the photosphere to be in the neighborhood of only 7,000° to 8,000° C. Furthermore, why omit to mention the summer anticyclones, in which the lowest strata, instead of being cooled near the ground, are decidedly overheated, so that the temperature gradients are exverted instead of inverted, while the earth would still appear dark, but with lower strata of greater emissive power?

If A represents the adiabatic rate of cooling, then B stands for the winter and C for the summer anticyclonic gradient. An examination of the Table 147, II, page 726 of the International Cloud Report of the United States Weather Bureau, 1899, gives the details of these two types of temperature inversion. We can not assume that the surface of the sun would, like the earth, appear dark if seen through a rift in the photosphere, and there is nothing to be gained on clearing the solar sky by descending currents. Since the earth is a better absorber and radiator of heat than the atmosphere in contact with it, the surface oscillations of temperature are much greater than they are at a little distance above it, but there is nothing to match this part of the analogue in the case of the sun. **Von Oppolzer** sees in the slow spiral approach of currents from the solar poles toward the Tropics the source of his anticyclonic currents. We have shown in the Cloud Report that anticyclonic and cyclonic circulations and the attendant phenomena are very shallow, compared with the total depth of atmosphere, being confined, practically, to the lowest 3 or 4 miles, and that they are always produced by the counter flow of powerful horizontal currents. It is evident that an observer outside the sun should be able to see quite a different type of phenomena from what is actually observed if the anticyclonic theory is correct.

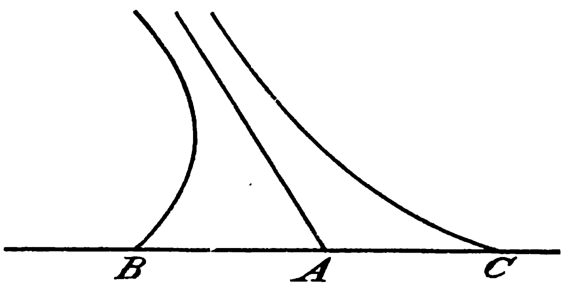

CHART 17.—Types of inversion and exversion gradients.

Secchi explains the spots as the descending products of condensation of material which has previously been ejected from the photosphere near the spot but not at it. It has seemed to me that since the history of irruptive prominences can be so minutely observed in all details from the beginning to the end, and since all the conspicuous movements near the spots, such as the faculæ bridges, the falling of photospheric matter into the umbra, the motions in the penumbra and the umbra have been carefully described, that if any such vertical circulation as **Secchi** required really exists, it must be generally visible to careful scrutiny. Otherwise, several of the difficulties attaching to the **Faye** and the **Von Oppolzer** theories apply with equal force to **Secchi**'s explanation of the local darkening of the solar photosphere.

GENERAL VIEW OF SOLAR METEOROLOGY.

The darkening of the photospheric clouds has been assigned to several causes: (1) The inability of the dissociated gases in the interior of the sun to emit radiant light, as the result of the destruction of molecular vibrations. This hypothesis breaks down, however, from the fact that such rifts in the photosphere should show a transparent opening clear through to the opposite side of the spherical envelope. (2) To the condensation of the upper layers of the photosphere by the radiation of heat to space. This theory fails quantitatively, because the radiation into space at that stratum is not equal to the supply of heat derived from the lower layers. By analogy, terrestrial clouds do not form by the radiation of heat into space, but by the expansion of currents ascending to strata of lower pressures. (3) To a screen formed by cooler gases descending from a sufficient height above the photosphere. This does not apply with sufficient generality to the solar surface, because spots should then be formed always under the debris of falling matter ejected in the irruptive prominences and other similar phenomena. (4) To electrical action, which need not be further considered as a primary cause of cloudy condensation, though we know it may modify the number of nuclei upon which the vapor is deposited. (5) To thermodynamic expansion from the unsaturated to the saturated stage, in rising from levels of a given initial pressure to those of diminished pressure. This view seems to me to be the correct one regarding the formation of the entire photosphere as a cloud shell at the end of a cooling radius, whose place is determined by the initial pressure, temperature, and vapor tension of the base of the vapor columns, which originate nearer the center of the sun. We would press the validity of the application to the explanation of the photosphere of the meteorological laws derived from the terrestrial atmosphere as regards the formation of cloud forms, especially the cumulus, which, if compacted and continuous around the entire earth, would present the appearance of wool pack and mottled forms to an outside observer, like those seen in the granulation and dark pores over the solar disk. The physics of this theory is so well known and has been so often alluded to in this connection that we may at once pass to the special point in view, namely, the peculiar type of condensation seen in the sun spots themselves. If in general the cloudy surface of the sun represents the first condensation at the end of the α stage and the beginning of the β stage, or the unsaturated and the saturated vapor stages, respectively, then we propose to see in the spots the next process in which the vaporous condensations begin to coalesce into metallic conditions akin to the formation of rain precipitation within the earth's cumulus stratum. More strictly, the analogous state in terrestrial meteorology is not the cyclonic (FAYE) nor the anticyclonic (VON OPPOLZER) types of middle latitudes, nor the anomalous forms of condensation by extraneous falling material (SECCHI), but simply the precipitation products peculiar to the tropical regions. For these most closely represent solar conditions, with the excessive heat and vigorous evaporation, with ascending currents free from general gyration, which condense at a height determined by the three elements mentioned, and then fall back in heavy, long-continued precipitation. This vertical convection is the only natural process that prevails where powerful horizontal currents of circulation do not exist, since these are the chief causes of the existence of high and low pressure areas and their attendant phenomena in the middle latitudes. Seen from above, these precipitation areas appear darkened, as compared with the adjacent regions where local condensation has not proceeded to the stage of liquefaction.

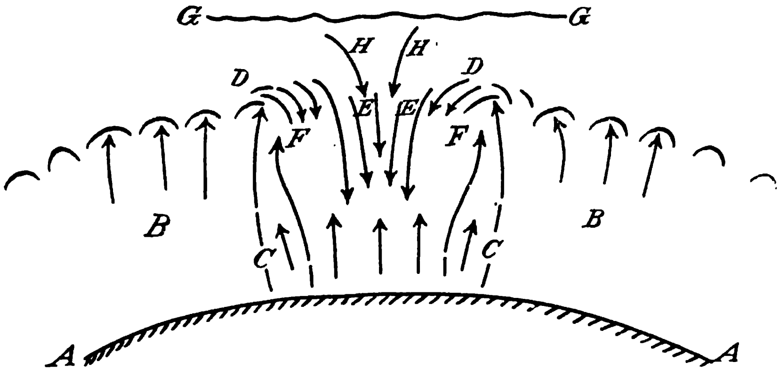

CHART 18.—Typical circulation in the formation of a solar spot.

Let *A* represent the surface of an interior nucleus of gases at very high temperature, and yet condensed to a viscous state by intense gravitational pressure, *B* the ascending currents whose heads form the cloud top of the cumulus type, *CC* especially vigorous ascending unsaturated currents which at the beginning of a spot formation may rise somewhat above the average level of the photosphere as *DD*. The true precipitation begins with a breakdown in the photosphere, the condensation products of the *DD* elevation falling back toward *AA* and carrying the cooler material in more condensed (liquid) form downward. This material begins to absorb heat in its downflow, but being in part liquid gains an increase of temperature only after the latent heat of vaporization is satisfied, and thus arrives at such levels as *EE* with a temperature lower than the ascending neighboring strata. This descending current within the body of the photosphere has such an individuality, derived from its different temperature, that it will thrust to one side the ascending elements *CC* which are rising on the periphery of the downflow *EE*. The upflow, however, must recurve at some higher level *DD* so that *CDFE* forms a local typical circulation whose energy is derived from within, not without (SECCHI), in which there is calm, and no gyration (FAYE), where the inner portions are cooler, consisting of a mixture of vapor and liquid returning to vapor. We mean to identify the highest parts of the recurving current with the elevated portions of sun spots seen in projection on the limb, radiating heat as if located higher than the photosphere, having about the shape suggested by Professor HALE; the inflowing portions *FF* constitute the penumbra, composed of a mixture of vapor and liquid, and thus radiating in radial streaks; the descending darkened portions *EE* form the umbra, which fails to radiate the average amount of heat, because this is absorbed in turning the liquid portions into vapor; it has a tubular form at times, or a flat form when the downflow is less violent, or even a form with convex upper surfaces when *DD* coalesces in an arch before the breakdown occurs; it displays quiescence of the gross materials as seen in the midst of the spots, but the congested molecular actions noted in the widening and thinning of the spectrum lines. Above this level may float the faculæ *GG* generally independent of the spot action; or the material just above the photosphere *HH* may converge and drift toward the umbral regions, and be drawn into it like faculous bridges which have been seen to disappear in the descending torrent. Enough has perhaps been said to indicate a theory of spot formation which includes to a remarkable degree all the details observed to be associated with them, and which also avoids many of the difficulties connected with the other points of view. This physical condensation theory is opposed to **Brester**'s chemical combination theory with its train of deceptive illusions and half-truth explanations of several facts of observation; to all the theories which make the darkness of spots due to local relative overheating of the photosphere; to **Oppolzer**'s, where the additional heat is due to adiabatic compression of descending currents; to **Evershed**'s, where additional internal heat in places with greater emissive power and higher temperature causes a general shortening of the spectrum, and shifts the wave lengths slightly toward the ultra-violet, after which a second shift backward is caused by absorption in the terrestrial atmosphere; to **Secchi**'s, where the absorption of light is caused by cooled gases descending from levels high above the photosphere, bringing the temperature of the upper strata with them; to **Faye**'s, where the ascending currents inside the photosphere must yet possess distinct cyclonic gyrations. It approximates in physical principle to **Sidgreave**'s adiabatic condensation, but shows more clearly how to differentiate the structure of the photosphere from that of the penumbra and umbra, respectively, by introducing a circulation limited by the top of the photosphere and the interior nucleus. The mixture of vapor and liquid in this circuit, especially in the levels of the photosphere, has the property of maintaining a nearly uniform temperature, being that of the vaporization of the liquid drops, while the precipitation is falling back toward the nucleus through considerable vertical distances. Hence the penumbra, being the top of the recurving circulation, radiates laterally from the stream, which is seen at right angles to its course, and manifests the alternate gaseous and gaseous-liquid portions which flow side by side if not intimately mixed; but the umbra shows the same streams end on, and as they retain the temperature of the locus of liquefaction, which is near the top of the photosphere, for some distance during their descent, the umbra is the region of relative coolness as compared with the adjacent photosphere. The causes which produce special evaporation in the sun-spot belts are bound up with the general circulation of the solar material, just as the rain belt of the Tropics is the result of the earth's atmospheric movements. These two circulations can not, however, have much in common, because in the case of the earth's atmosphere the difference of temperature between the equator and the poles is the cause of powerful horizontal gradients, and the corresponding well-known general circulation over the hemisphere, with the dependent local cyclones and anticyclones; while in the case of the sun the temperature variations must be chiefly in vertical directions, which, on a rotating sphere, will produce a special type of circulation.

The phenomenon of the veiled spots which are seen in all latitudes indicates that the vertical precipitation in these cases occurs only on the under side of the photosphere, and does not penetrate the entire thickness of it except in the spot zones. This may mean that the condensation is more vigorous or else that the photosphere is thinner in the spot zones than in the other regions outside of them.

THE CONVECTION STREAMS IN THE INTERIOR OF THE RADIATING AND ROTATING SUN.

The sun is a rotating body which is cooling by radiation from the interior masses, and is permeated by convective streams which tend to restore the thermal equilibrium wherever it is broken up by changes in the heat contents. It is important to have a general conception of the form of the thermal lines of flow for the sake of governing the direction in which the physical theories must be constructed. Prof. H. von **Helmholtz** has entered upon this problem as regards the earth's atmosphere in his well-known paper on Atmospheric Movements.* R. **Emden** has used these equations and made an application of them to the interior of the sun with commendable success.* These papers are too complex to reproduce even as a summary in this place, but they are important for all students of the solar and terrestrial physical problem.

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* "Sitzungsberichten" of the Royal Prussian Academy of Science at Berlin, 1888, May 31, pp. 647–663." Translation by Prof. Cleveland Abbe, in his Mechanics of the Earth's Atmosphere, pp. 78–93.

Change the German notation into that adopted in my standard system, and especially as follows in cylindrical coordinates:

Angular momentum	$\Omega=\omega r^2$ to $\Omega=\omega\varpi^2$.
Radius vector from the center	R to r. (Bigelow).
Distance from axis of rotation	r to ϖ.
Axis from which angular velocity is reckoned	y to x.
Axis at 90° in right-hand rotation	z to y.
Axis of rotation	x to z.
Velocities	v to u. w to v. u to w.
In the hydrodynamic equations, pressure	p to P.
In the thermodynamic equations, gas constant	Π to R.

We obtain, neglecting the terms due to the deflecting force of rotation, $+2\omega v$ along x, $-2\omega u$ along y, the equations:

$$\text{Velocities } u=-\omega y=-\frac{\Omega}{\varpi^2}y. \qquad \text{Accelerations } \frac{dV}{dz}+\frac{1}{\rho}\frac{dP}{dz}=0.$$

$$v=+\omega x=+\frac{\Omega}{\varpi^2}x. \qquad \frac{dV}{d\varpi}+\frac{1}{\rho}\frac{dP}{d\varpi}=\frac{\Omega^2}{\varpi^3}=\frac{v^2}{\varpi}.$$

$$w=0$$

It is evidently a mistake to neglect the deflecting forces in comparison with the centrifugal force, especially in view of the fact that they will determine a right-hand rotation to all vortices in the northern hemisphere, and a left-hand rotation to all vortices in the southern hemisphere, and will thus construct the filaments having opposite rotations in the two hemispheres of the sun.

The thermodynamic equations

$$\frac{p}{\rho}=RT \qquad \text{and } \frac{p}{p_0}=\left(\frac{\rho}{\rho_0}\right)^k$$

are now introduced and carried forward with θ and π as abbreviations to the forms,

$$dV+\theta\frac{d\pi}{dz}=0\,.$$

$$\frac{dV}{d\varpi}+\theta\frac{d\pi}{d\varpi}=\frac{\Omega^2}{\varpi^3}=\frac{v^2}{\varpi} \quad \text{where } v=\text{the linear velocity of rotation.}$$

This becomes in a homogeneous layer,

$$V+d\pi=-\frac{1}{2}\frac{\Omega^2}{\varpi^2}+C.$$

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* Sitzungsberichten der mathem.-physic. Classe der Kgl. bayer. Academie der Wissenschaften, Bd. XXXI 1901 Heft III. Translation in the Astrophysical Journal, January, 1902, pp. 38–59.

For surfaces of discontinuity, $\pi_1-\pi_2=0$. The equation of this meridian curve of discontinuity is,

$$V\left(\frac{1}{\theta_2}-\frac{1}{\theta_1}\right)=\frac{1}{2\varpi^2}\left(\frac{\Omega_1^2}{\theta_1}-\frac{\Omega_2^2}{\theta_2}\right)-\frac{C_1}{\theta_1}+\frac{C_2}{\theta_2}.$$

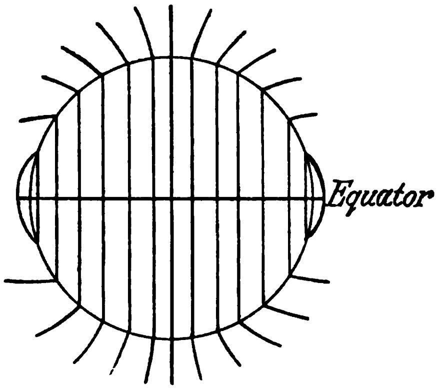
The direction of the tangent to this meridian curve is given by

$$\frac{d\varpi}{dr}=\varpi^3\frac{dV}{dr}\left(\frac{\theta_2-\theta_1}{\Omega_1^2\,\theta_2-\Omega_2^2\,\theta_1}\right).$$

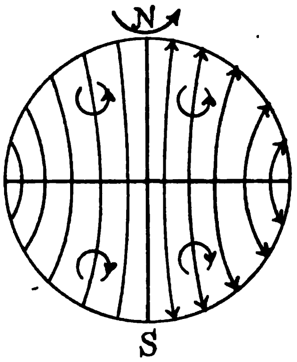
For the derivation and discussion of these equations compare VON HELMHOLTZ and EMDEN throughout.

It is necessary to remark that the pressure P in the hydrodynamic equations is not the same as p in the thermodynamic equations, since P is pressure in units of force of acceleration, and p is pressure as weight or mass in grams or kilometers. If the same unit system is maintained in both sets of equations, as is apt not to be the case in meteorology, then $P=G.p$ where G is the force of gravity at the place of discussion in the interior of the sun. This factor seems to have been neglected by EMDEN, but its introduction would only change the constants involved in θ, and not the form of the curves, so that it does not affect the conclusions.

The result of the discussion is as follows:



Uniformly magnetized sphere.



Convectional circulation within the sun.

Along the surfaces of discontinuity the convectional movement starts from the interior in waves, but these soon turn into vortices more or less columnar in general formation. They begin at the solar equator and extend toward the surface in curves which are symmetrical to the axis of rotation, but diverge from it more and more in advancing from the equator to the surface. Thus the sun is lamellated in vortical filaments at right angles to the equator, and the vortices must rotate in opposite directions in the two hemispheres under the influence of the deflecting force due to the rotation of the sun on its axis. It is not probable, as EMDEN supposes, that this rotation involves very widely extended areas in cyclonic whirls, such as would produce sun-spot regions, but rather that the powerful vertical convection generates small and violent vortex tubes whose axes follow the lines of the diagram approximately.

From this we make the following important deductions: (1) The true angular rotation of the sun is that at the equator, and it is the same at the poles. In the middle latitudes the angular velocity is retarded at the surface of the sun, as in the spot belts, because the convectional tubes bring up an initial angular velocity from nearer the axis of rotation on the equator. (2) From the recent development of physical researches the atoms of matter are associated with ionic electric charges, or even composed of numbers of such electrons. These move in orbital rotation like satellites, and the periodic motion of the electric charges produces a magnetic field. Compare paper by **Sutherland**, The Cause of the Structure of Spectra, Phil. Mag., Sept., 1901; and paper by J. H. **Jeans**, The Mechanism of Radiation, Phil. Mag., Nov., 1901. **Jeans** writes:

> If an atom consists of n negative and $n+s$ positive ions, the total charge on the atom will be se, and may be referred to as the valency of the atom. * * * *Electrodynamic forces.—Permanent and induced magnetism.*—Electrodynamic forces will arise from the motions of the atoms or molecules. Each molecule of a solid will in addition to its *internal* and *translational* vibrations possess a *rotational* vibration in the field of intermolecular force. As we pass to greater amplitudes of this vibration, we shall come to a point at which a vibration through a finite angle gives place to a complete rotation. The rotation is not of uniform velocity, since irregularities are introduced by the field of force. *In a rotating atom or molecule we have the rotation of a system of charges of electricity. The net result is therefore equivalent to a circular current of electricity in the direction of rotation.* Hence in the case of vibration the result is emission of electromagnetic waves; but the force on the molecule or atom varies in direction at each half-phase. *In case of a complete rotation the current and forces are of constant direction; the atom or molecule may be regarded as a permanent magnet of moment proportional (except for irregularities) to the angular velocity, and of axis coinciding with the axis of rotation.* In general, the axes of these molecular magnets will be distributed at random, so that the solid will exhibit no magnetic properties. If the solid is placed in a magnetic field, there will be a couple on each such magnet, tending to turn its axis of rotation parallel to the lines of magnetic force.

Further effects are discussed by **Jeans** in his interesting paper.

The effect of the rotating vortices in the interior of the sun will be to turn the atoms and molecules around their axes, and thus to polarize them, so that in consequence the entire mass of the sun will become magnetized and generate an external magnetic field. The high temperature, great internal pressure, and the filamentary vertical convection just mentioned are highly favorable for the production of such internal magnetization in the sun. (3) It will be remembered that in my earlier researches on these subjects I determined that the synodic rotation period of the sun is 26.68 days at the poles, which is the same as that of the visible equator, while the belts in middle latitude show a distinct retardation to about 27.30 days. The parallelism between the filamentary structure of the sun and the distribution of the lines of force in the interior of a uniformly magnetized sphere, shown on the diagram, is too striking to be overlooked. The rotating masses carrying the electric charges in vortical filaments in opposite directions in the two hemispheres will generate a positive magnetic field in the northern, and a negative magnetic field in the southern hemisphere of the sun. This is in accord with the results of my discussion of the components of disturbing forces in the earth's magnetic field, which concluded that the northern hemisphere of the sun is positively magnetized. The periodic and aperiodic magnetic disturbances at the earth are consequently effects and measures of the convective circulation within the sun. It seems to me, therefore, that this view appears to overcome the objection that a hot body like the sun can not be magnetized, and that it strengthens the hypothesis that all large cosmical bodies which are cooling by radiation must also have magnetic properties. The subject thus briefly outlined is worthy a much fuller exposition, but it is necessary to pass on to further evidence which is in harmony with this theory of a magnetized sun.

THE CHROMOSPHERE, REVERSING LAYER, PROMINENCES, AND FACULÆ.

Having shown how the appearances displayed by the photosphere and spots can be explained on simple meteorological principles adapted to solar pressures and temperatures, we proceed to discuss the phenomena of the chromosphere, reversing layer, prominences, and faculæ in a similar way, by an appropriate extension to the higher regions of the sun's atmosphere. The prominences and spots occur at the level of the cloudy condensation, at considerable distance above the invisible solar nucleus, and involve primarily the processes of saturation represented by the β stage, wherein a mixture of gas and vapor reaches the pressure and temperature which changes the vapor contents of metals into liquid drops, held in suspension or precipitated according as the pure stage is retained, or as a portion of the material falls by gravitation. If these metallic substances have also a solid state, corresponding to ice in the analogue of aqueous vapor, so that they pass into liquid drops at the cumulus levels and into solids at the cirrus levels, then it will be expected that at some elevation above the photosphere there will be found in the atmosphere of the sun certain condensations resembling the formation of ice at the cirrus levels. The chromosphere is probably the extension of the purely gaseous atmosphere which rests upon the nucleus in which the photosphere floats at one level and the faculæ at a higher level, and it is seen to reach to the distance of about 6″=6 seconds of arc=4,350 kilometers=2,703 miles above the photosphere. The reversing layer is supposed to be a thin stratum of the chromosphere near the photosphere, where the conditions of the atoms and their electric charges are favorable as regards temperature and pressure for giving off electro-magnetic light waves. These are in part absorbed in the upper portion of the chromosphere and produce the Fraunhofer dark lines of the solar spectrum. This view is so plain that it is only necessary to compare the possibilities of its development with the detailed observations on the prominences and faculæ, to test the value of it in accounting for the facts. The other theories which have been recently discussed are the chemical theory of dissociation and association of the chemical elements, (1) either into primordial subatoms, or, (2) into the ordinary constituent elements of inorganic compounds; the ballistic theory of hydrogen bombs with the accompaniment of explosive expansion in free space; the incandescence and illumination of meteoric matter or solar products which collects and circulates about in the upper levels; the electrical-discharge theory in rarified gases; and the anomalous-refraction theory of Wood at the base of the chromosphere. The chemical theory requires an atmosphere of considerable density, reaching to the uttermost extensions of the corona; the ballistic theory demands that the atmosphere should really cease at about the level of the top of the chromosphere; the minute solid particles in the incandescence theory that there be no atmosphere; and also the electrical-discharge theory that there be at most an extremely attenuated atmosphere.

The facts to be accounted for may be briefly summarized as follows: The prominences are seen to extend from the photosphere upward through the chromosphere to a distance of at least 600″; that is, one hundred times the height of the chromosphere. The forms are fantastic and extremely varied, but suggest powerful uprushes of gas, chiefly hydrogen and calcium, from below, which also falls back to the chromosphere; enormous velocities, such as 100 to 200 kilograms per second commonly, and 400 to 500 kilograms per second occasionally, are observed in the displacement of the spectrum lines. Such remarkable heights and extreme velocities are attained that it seems almost incredible that gaseous matter can really be made to pass through such transformations. Often the transitions are so sudden in their formation and disappearance as to suggest an optical appearance of temporary luminescence of tranquil matter lying in quiescent strata as arranged by gravitation; especially do the phenomena of quiescent prominences, which are destitute of violent motions and are seen to form and disappear *in situ*, seem to contradict the theory of violent eruptions. The metallic lines predominate near the base of the chromosphere, while lines of the lighter elements more frequently reach the higher strata. The observation of great velocities continued for a considerable time but with no displacement of the relative position of the prominence, is an argument against the actual movement of materials. There should be heat flushes accompanying the irregular action of congested radiation emitted from a viscous nucleus which extends upward through the atmosphere and into distant spaces. The prominences, which have a distinct columnar body, are often surrounded by a thin white sheath, forming the white prominences, which is no doubt caused by surface radiation from the column, with condensation of the gaseous material into liquid or solid states that reflect polarized light emitted from other sources. The prominences decay from the outside toward the interior, just as clouds dissolve in the earth's atmosphere. The temperature gradients on the sun are generally vertical, since it is probably radiating equally in all directions; but there are also local variations of temperature, and in consequence temporary horizontal circulations needed to readjust the disturbed equilibrium of the strata. The anomalous angular motion of the photosphere is probably due to some permanent law of radiation not yet worked out, and this can be best determined by an accurate knowledge of the rotation periods in the different strata of the sun's atmosphere after the confusion now prevailing in the measures has been cleared up. Much importance has been attached to the effect produced by the material accompanying the ascending currents when it falls back to the chromosphere, and the extreme horizontal velocities noted in the line of sight are taken to be caused by the collisions of ascending and descending streams. If meteoric matter or collections of solar dust exist in the region above the chromosphere, then they must shine in the state of incandescence to which the particles are raised by the high temperature prevailing in the neighborhood of the sun. To all these forces and conditions we must add the electrical and magnetic forces which are admitted by many students of solar physics to exist in the sun's atmosphere after the analogue of atmospheric electricity and magnetism.

Such a review of solar phenomena seems to indicate the coexistence of several typical processes, and this is natural under the very complex conditions of matter near the sun. I shall state my conclusions briefly rather than discuss each point, because it is my purpose to present the case generally, with the object of building up a view which will be valuable as a working hypothesis.

There are distinct evidences of genuine uprushes of gaseous matter attaining great altitudes and velocities, not so much due to sudden ballistic ejection as to continuous pressure along a line of escape from a congested interior region. These are the eruptive prominences, which cool from without inward in the free space above the chromosphere, deposit fine dust cooled first as a white sheath on the surface under quick lateral radiation, and then throughout the mass, which is subjected to illumination by reflected and polarized light and to incandescence by the radiation prevailing in the region. These dust particles form the nuclei of electric charges derived by induction from the region of the chromosphere and photosphere, and these produce the quiescent prominences which come and go in fantastic forms, under the variable electrostatic forces operating upon them. The enormous lateral velocities may thus be due to local electrostatic attractions and repulsions, and they may be said to resemble the phenomena in rarefied discharge tubes, for the same reasons which are applicable by known physical laws. This metallic dust can be seen at times to settle back to the chromosphere, and it may be inferred that when that level is attained, after the lapse of more or less time, the dust becomes entangled in the true gaseous envelope, and being thus held in suspension becomes the material of which the faculæ are composed. Just as the fine ice particles in the earth's atmosphere produce the cirrus formations, which remain for long periods at high levels and appear or are extinguished with the local variations of temperature and change in the state of saturation, so the faculæ have a very similar history. This material may also be supplied at first hand by the product of eruptions from the photosphere, occurring generally near the sun spots, but which does not have impetus enough to pass beyond the chromosphere. The faculæ have about the same spectrum as the prominences; they float in irregular reticulations in levels above the photosphere; they are carried about in the local currents of that region; they appear and disappear rapidly with the change in temperature as the local radiation of heat is modified; they shine partly by reflected light, partly by their own incandescence, and also in part by a sort of phosphorescent or radio-active influence from the neighboring strata, not unlike the electric glow which sometimes illuminates clouds and elevated portions of the earth's atmosphere.

The purpose of this sketch of solar meteorology in parallelism with terrestrial meteorology is to show how closely the general and the particular phenomena can be derived from the simplest possible transformation of gases and metallic vapors through the α . β . γ . δ . stages, which are well known in meteorology. It dispenses entirely with improbable hypotheses; but, specifically, it becomes important to make the attempt to apply the laws of condensation to the solar elements. It is believed that an adaptation of the formulæ and processes developed in the International Cloud Report, Weather Bureau, 1899, to solar physics will result in at least approximately solving the questions involved. As this is a work of considerable magnitude and difficulty, we can not expect to accomplish it immediately. Meanwhile it is important to secure as definite data as is possible regarding the pressures, the temperatures at the different levels, and especially the average height of the faculæ reticulation above the photosphere. Some conception of the broad facts may be given as follows:

THE SOLAR FUNDAMENTAL CONSTANTS.

TABLE 14.—*Fundamental Constants.*

[FOR A HYDROGEN SOLAR ATMOSPHERE AND A DRY AIR TERRESTRIAL ATMOSPHERE.]

[Kilogram—meter—second—centigrade degree system.]

Formulæ.			The solar constants.		The terrestrial constants.	
				Logarithms		Logarithms
Radius		R	696847300 m.	8.8431376	6370191 m.	6.8041503
			433000 miles	5.6364879	3958.226 miles	3.5975006
Gravity		g_o $\frac{g_o\,(\text{sun.})}{g_1\,(\text{earth.})}=27.6$	270.6456 m.	2.4324010	9.8060	0.9914919
Coef. in lat.		k			0.00260	7.41497 −10
Coef. in alt.		$1+\eta=1+\frac{KM}{R}$	1.004547	0.0019702	1.00157	0.00068
Modulus		M	0.4342945	9.6377843−10	0.4342945	9.6377843−10
Weight per unit volume	Mercury	σ_m (Kilog. per cu. meter.)	13595.8 kilo.	4.1334048	13595.8 kilo.	4.1334048
	Water	σ_1	1000.	3.00000	1000.	3.00000
	Air	σ_o	1.29305	0.1116153	1.29305	0.1116153
	Hydrogen	σ_h	0.089996	8.9542245−10	0.089996	8.9542245−10
	Calcium	σ_c				
Specific weight	Mercury	ρ_m (grams per cu. cm.)	13.5958	1.1334048	13.5958	1.1334048
	Water	ρ_1	1.000	0.00000	1.000	0.00000
	Air	ρ_o	0.00129305	7.1116153	0.00129305	7.1116153
	Hydrogen	ρ_h	0.000089996	5.9542245−10	0.000089996	5.9542245−10
	Calcium	ρ_c				
Barom. const.		$B_n=\frac{p_o}{\sigma_m}$	20.9760 m.	1.3217227	0.760 m.	9.8808136−10
Homog. Atmos.		$l=\frac{\sigma_m B_n}{\sigma_h}=RT$	8168860 m.	6.5009030	7991.04 m.	3.9026031
			1969.085 miles	3.2942533	4.9654 miles	0.6959534
Barom. const.		$K=\frac{l}{M}=\frac{\sigma_m B_n}{\sigma_h M}=\frac{RT}{M}$	7296570	6.8631187	18400.	4.2648188
Pressure in units of force		$P_o=g_o\rho_h l=g_o\rho_m B_n=g_o\rho_h p_o v_o=\frac{g_o p_o}{\sigma_1}$	77184.22	4.8875285	101.324	2.00571
Pressure in units of weight in kilo. per sq. met.		$p_o=\sigma_1\rho_h l=\sigma_m B_n=\sigma_1\rho_m B_n=\frac{\sigma_1}{g_o}P_o$	285185.5	5.4551275	10333.	4.0142184
Volume		$v_h=\frac{1}{\sigma_h}$	11.1116	1.0457755	0.77336	9.8883847−10
Equ. of elasticity		$p_o v_n=l=RT$	8168860	6.5009030	7991.04	3.9026031
Gas constant hydrogen		$R=\frac{\rho_o v_h}{T}=\frac{\rho_m B_n}{\rho_h T}$	420.552	2.6238197	29.2718	1.46644
Temp. photos.		T	7585C°	3.8770833	273C°	2.43616
Temp. grad. per 1000 meters		$-\frac{dt}{dh}=\frac{1}{P_o}$	0.0129562C°	8.1124715−10	9.869C°	0.99429
Coef. of expans.		a	0.00367 at T=273°		0.00367	7.56467 −10

Table 15.—*Computation of the relative intensity, total intensity, absolute temperature; also the temperature of a small black sphere at different distances from the sun.*

Cosec $\varphi = \frac{R+d}{R}$. Relative intensity $= \frac{\sin^2 \varphi_1}{\sin^2 \varphi_2}$. At earth = 1.

Distance—										
from surface d	0″	6″	10″	17″.5	35″	175″	350″	397″.6	480″	700″
from center										
$(R+d)$	960″	966″	970″	977″.5	995″	1135″	1310″	1357″.6	1440″	1660″
log $R+d$	2.98227	2.98498	2.98677	2.99012	2.99782	3.05500	3.11727	3.13278	3.15836	3.22011
log R	2.98227	......	......	......	......	......	......	......	......	......
cosec φ	0.00000	0.00271	0.00450	0.00785	0.01555	0.07273	0.13500	0.15051	0.17609	0.23784
φ	90°	83 36.5	81 46.0	79 8.3	74 45.5	57 45.5	47 8.6	45 0.0	41 48.6	35 19.9
sin φ	0.00000	9.99729	9.99540	9.99215	9.98445	9.92727	9.86514	9.84949	9.82391	9.76216
$\sin^2 \varphi$	0.00000	9.99458	9.99080	9.98430	9.96890	9.85454	9.73028	9.69898	9.64782	9.52432
$\sin^2$ 15′ 59″.63	5.33536	......	......	......	......	......	......	......	......	......
	4.66464	4.65922	4.65544	4.64894	4.63354	4.51918	4.39492	4.36362	4.31146	4.18896
Rel. intensity	46200	45627	45231	44559	43007	33051	24827	23101	20486	15451

Total intensity of emission in gr. cal. per sq. cm. per minute. $J_{\circ} = \pi q \sin^2 \varphi$;
$J_{\circ} = 4.0$ at upper limit of earth's atmosphere; $q = 58780$.

log π	0.49715	......	......	......	......	......	......	......	......	......
log q	4.76923	......	......	......	......	......	......	......	......	......
$\sin^2 \varphi$	0.00000	......	......	......	......	......	......	......	......	......
log $J_{\circ}$	5.26638	5.26096	5.25718	5.25068	5.23528	5.12092	4.99666	4.96536	4.91420	4.79070
$J_{\circ}$	184660	182370	180710	178110	171900	132110	99234	92334	82073	61759

Effective temperature of a plane surface $T^4 = \frac{J_{\circ}}{\sigma \times 60}$; $\sigma = 1.277 \times 10^{-12}$ per second.

log $\frac{1}{\sigma \times 60}$	10.11464	......	......	......	......	......	......	......	......	......
log T^4	15.38102	15.37560	15.37182	15.36532	15.34992	15.23556	15.11130	15.08000	15.02884	14.90534
log T	3.84526	3.84390	3.84296	3.84133	3.83748	3.80889	3.77783	3.77000	3.75721	3.72634
T	7003	6981	6966	6939	6878	6440	5996	5888	5718	5325

Effective temperature of a small spherical black body $T_1^4 = \frac{J_{\circ}}{\sigma \times 4 \times 60}$.

log $\frac{1}{\sigma \times 4 \times 60}$	9.51258	......	......	......	......	......	......	......	......	......
log T_1^4	14.77896	14.77354	14.76976	14.76326	14.74786	14.63350	14.50924	14.47794	14.42678	14.30328
log T_1	3.69474	3.69339	3.69244	3.69082	3.68697	3.65838	3.62731	3.61949	3.60669	3.57582
T_1	4952	4936	4925	4907	4864	4554	4239	4164	4043	3766

Distance—	1 R	2 R	3 R	4 R	5 R	6 R	7 R	8 R	**Earth.**	
from surface d	960″	1920	2880	3840	4800	5760	6720	7680	213.94 R	
from center										
$(R+d)$	1920″	2880	3840	4800	5760	6720	7680	8640	214.94 R	
log $R+d$	3.28330	3.45939	3.59550	3.68124	3.76042	3.82737	3.88536	3.93651	......	
log R	2.98227	......	......	......	......	......	......	......	......	
cosec φ	0.30103	0.47712	0.61323	0.69897	0.77815	0.84510	0.90309	0.95424	......	
φ	30° 0′.0	19 28.3	14 6.1	11 32.2	9 35.7	8 12.8	7 10.8	6 22.8	15′ 59″.63	**Auwers**
sin φ	9.69897	9.52288	9.38677	9.30103	9.22182	9.15490	9.09691	9.04576	7.66768	
$\sin^2 \varphi$	9.39794	9.04576	8.77354	8.60206	8.44364	8.30980	8.19382	8.09152	5.33536	
$\sin^2$ 15′ 59″.63	5.33536	......	......	......	......	......	......	......	......	
	4.06258	3.71040	3.43818	3.26670	3.10828	2.97444	2.85846	2.75616	0.00000	
Rel. intensity	11550	5133	2743	1848	1283	943	722	570	1	
log π	0.49715	......	......	......	......	......	......	......	......	
log q	4.76923	......	......	......	......	......	......	......	......	
$\sin^2 \varphi$	9.39794	......	......	......	......	......	......	......	......	
log $J_{\circ}$	4.66432	4.31214	4.03992	3.86844	3.71002	3.57618	3.46020	3.35790	0.60174	
$J_{\circ}$	46166	20518	10963	7387	5129	3769	2885	2280	4.0	
log $\frac{1}{\sigma \times 60}$	10.11464	......	......	......	......	......	......	......	......	
log T^4	14.77896	14.42678	14.15456	13.98308	13.82466	13.69082	13.57484	13.47254	10.71638	
log T	3.69474	3.60670	3.53864	3.49577	3.45617	3.42271	3.39371	3.36814	2.67910	
T	4952	4043	3457	3132	2859	2647	2476	2334	478	
log $\frac{1}{\sigma \times 4 \times 60}$	9.51258	......	......	......	......	......	......	......	......	
log T_1^4	14.17690	13.82472	13.55250	13.38102	13.22260	13.08876	12.97278	12.87048	10.11432	
log T_1	3.54423	3.45618	3.38812	3.34526	3.30565	3.27219	3.24320	3.21762	2.52858	
T_1	3501	2859	2444	2214	2021	1872	1751	1651	337.7	

TABLE 16.—*Summary of the temperatures and pressures at different distances from the surface of the sun.*

h=height		Distance from surface	Log h in kilom.	ΔT	7535−ΔT	T	J_o	Relative intensity	T_1 small sphere
Meters	Sec. arc								
				°	°	°			°
0	0''			0	7535	7003	184660	46200	4952
726.000	1''		2.86094	9.4	7526	7002	184621	46190	4949
4356.000	6''	Chromosphere	3.63909	56.4	7479	6981	182370	45627	4936
7260.000	10''		3.86094	94.1	7441	6966	180710	45231	4925
12705.000	17''.5	Diam. of earth	4.10397	164.6	7370	6939	178110	44559	4907
25410.000	35''.0	Top of inner corona	4.40500	329.2	7206	6878	171900	43007	4864
127050.000	175''.0		5.10397	1646.0	5889	6440	132110	33051	4554
254100.000	350''.0	Average corona	5.40500	3292	4243	5996	99234	24827	4239
288948.000	398''.0	$\varphi=45°$	5.46082	3744	3791	5888	92334	23101	4164
348480.000	480''.0	½ radius	5.54218	4515	3020	5718	82073	20486	4043
508200.000	700''.0	Limit of prominences	5.70603			5325	61759	15451	3766
696960.000	960''	1 radius	5.84321			4952	46166	11550	3501
1393920 kil.	1920''	2 radii	6.14424			4043	20518	5133	2859
2090880	2780''	3 radii	6.32032			3457	10963	2743	2444
2787840	3840''	4 radii	6.44527			3132	7387	1848	2214
3484800	4800''	5 radii	6.54218			2859	5129	1283	2021
4181760	5760''	6 radii	6.62135			2647	3769	943	1872
Earth		213.94 radii				478	4.0	1	337.7

Height in arc	$\log \frac{h}{K}$	$\log \frac{B_o}{B}$	$\frac{B_o}{B}$	B_o=5 atmos. B atmospheres
1/7''	8.15391	0.01425	1.033	4.838
1''	8.99782	0.09950	1.257	3.976
6''	9.77597	0.59700	3.954	1.265
10''	9.99782	0.99500	9.885	0.506
17''.5	0.24085	1.74120	55.11	0.091
35''.0	0.54138	3.47842	300.9	0.002
175''.0	1.24085	17.41200	2.58×10^{17}	
350''.0	1.54188	34.78420	6.08×10^{34}	
480''.0	1.67906	47.76000	5.75×10^{47}	
700''.0	1.84291	69.64833	4.45×10^{69}	

$$\frac{dt}{dh}=-0.0129562\ \text{C}^\circ \text{ per kilometer (1000 m), [8.11257].}$$

$$\log\frac{B_o}{B}=\frac{h-h_o}{K\,(1+\alpha\theta)\,(1+\beta)\,(1+\gamma)\left(1+\frac{h+h_o}{R}\right)(1+\eta)}=\frac{(h-h_o)\,n}{K}.$$

$$\log\frac{B_o}{B}=\frac{h}{K} \text{ for first approximation.}$$

Assume B_o=5 atmospheres=51665 kilog. per sq. meter.

We shall more readily reach definite ideas regarding the conditions of solar meteorology, at least approximately, by computing the constants on the sun for a hydrogen atmosphere which correspond with those on the earth for a dry-air atmosphere. This is easily done since the only changes required to pass from terrestrial to solar conditions are to make the force of gravity at the surface of the photosphere 27.6 times that at the surface of the earth, and to substitute for the weight of air per unit volume, σ_o=1.29305 kilograms per cubic meter, that of hydrogen, σ_h=0.089996. Table 14, "Fundamental constants for a hydrogen solar atmosphere and a dry-air terrestrial atmosphere," contains an exhibit of these principal meteorological relations. We are justified in taking hydrogen as the basis of the computation, because the spectrum shows that this element is most abundant in the chromosphere and up to the limits of the true gaseous envelope. Other constituents are mixed with it, as aqueous vapor and carbonic gas are mixed in the constituents of the earth's atmosphere. We may be able sometime to make the necessary modifications in order to introduce them into the formulæ. Under the columns headed

"Terrestrial constants" are given the values for the earth's atmosphere, selected from Table 64 of the International Cloud Observations. The corresponding solar constants are placed in the adjoining section. The several values are checked by an application of the numerous cross connections which are given in the formulæ, and they are therefore entirely self-consistent, so that all criticisms of the results heretofore obtained by other authors depend upon this entire body of systematic relations. All of the formulæ are well known, and the resulting values are easily verified, except the value assigned to the temperature of the photosphere to which the values are immediately applicable. From SCHEINER's Strahlung und Temperatur der Sonne, beginning with page 32, we make the following Table 17:

TABLE 17.—*The solar constant and the effective temperature of the sun.*

Authors	Year	The solar constant. Gram calories per sq. cm. per minute	The effective temperature of the sun
Pouillet	1837	1.793	° 5600
J. Herschel	1825	Same	...
O. Hagen	1863	1.9	...
Forbes	1842	2.82	...
Radau	...	1.82	...
Secchi	1860	...	5400
Violle	1875	2.590	6200
Soret	...	...	5500
Corva	1878	2.28 to 2.37	...
Langley	1884	3.068 2.630 to 3.505	6000
Rosetti	1878	...	10000
Abney and Festing	...	...	12700
Savelief	1889	2.86 to 3.47	...
Pernter	1889	3.05 to 3.28	...
Åugström	1890	4.00	...
Wilson and Gray	1894	...	6200
Paschen	...	...	5000
Scheiner	1899	...	7010

The modern reductions of the old observations and the most recent results agree in taking STEFAN's law for the total intensity of emission, which is the heat equivalent of total radiation emitted by a black body at the absolute temperature T. Compare Table 41, formula 6,

$$J_o = \int_o^\infty J d\lambda = \sigma T^4 = 1.277^{-12} T^4 \frac{\text{Gr. Cal.}}{\text{cm}^2.\text{ sec.}}$$

where σ is KURLBAUM's value of the constant. SCHEINER's formula for computing the effective temperature is:

$$T = 273 \sqrt[4]{\frac{2.483}{\sin^2\varphi} \cdot \frac{J_o}{h_1}}$$

The effective temperature is that of an absolutely black body of equal apparent diameter to that of the sun and of equal radiation efficiency. The angle for a distant point *d* from the surface of the sun is readily computed as follows:

Let R = the radius of the sun.
d = the distance from the surface.
φ = the apparent semidiameter at the distance d.

Then, $\operatorname{cosec} \varphi = \frac{R+d}{R}$.

In Scheiner's formula,

$$2.48 = \left(\frac{373}{273}\right)^4 - 1.$$

J_0 = the solar constant = 4.00 gram calories per square centimeter per minute, received on the outer surface of the atmosphere.

$h_1 = 1.056$ the ratio of the radiation of a black body at 100° C. to one at 0° C.

$\varphi = 31' \, 59''.26$ (Auwer's), the angular diameter of the sun as seen from the earth.

With these auxiliary quantities the temperature of the sun is computed to be 7003° C. This is, however, the temperature outside the sun's atmosphere, and does not allow for the solar atmospheric absorption. If this is added, it is supposed that the solar constant should be increased from 4.0 to 6.0; in this case the effective temperature of the photosphere would be 7730° C. Now, in computing the gas constant of hydrogen, we have, $R = \frac{\rho_m B_n}{\rho_h T}$. Taking $B_n = 9.860$ m. and $T = 273°$, the standard conditions at the surface of the earth, $R = 420.552$; the corresponding conditions at the surface of the sun being $B_n = 270.6456$, $T = 7535°$ C., then $R = 420.552$. This computation of the temperature 7535°, in so close agreement with the most probable values as derived from Stefan's law and the solar constant at the earth, has induced me to adopt $T = 7535°$ for the sake of the gas constant of hydrogen. This may be a coincidence only, but yet it serves to systematize the solar and the terrestrial constants, for hydrogen and air respectively, in a single numerical scheme. The effective temperature of a small black spherical body exposed to radiation is one-fourth that of a plane surface having an area equal to that of a circular section through the center of the sphere. This is due to the fact that the radiation received on a given area is emitted through four times that surface, since the radiation is lost equally in all directions from the sphere. The relative intensity of bodies situated at such distances that the apparent semidiameter of the sun is φ_1 and φ_2 is in the proportion $\frac{\sin^2 \varphi_1}{\sin^2 \varphi_2}$. The total intensity of emission in gram calories per square centimeter per minute is $J_0 = \pi q \sin^2 \varphi$, where $q = 58780$ and $J_0 = 4.0$ at the upper limit of the earth's atmosphere. The temperature gradient becomes,

$$\frac{dt}{dh} = -\frac{1}{P_0} = -0.0129562° \text{C.},$$

as computed from

$$\frac{1}{P_0} = \frac{1}{g_0 \rho_h l} = \frac{1}{g_0 \rho_m B_n}$$

for a hydrogen atmosphere. This gradient may be used within the sun's true atmosphere setting out from $T = 7535°$ at the photosphere. Finally, we have the formula for the barometric pressure at different heights:

$$\operatorname{Log} \frac{B_0}{B} = \frac{h - h_0}{K(1+\alpha\theta)\,(1+\beta)\,(1+\gamma)\left(1 + \frac{h+h_0}{R}\right)(1+\eta)}.$$

The term $(1+\beta)$ is due to the admixture of other gases with the hydrogen and can not be evaluated; $(1+\gamma)$ is the variation of the solar gravity with the latitude and is generally negligible in preliminary discussions; $\left(1 + \frac{h+h_0}{R}\right)$ can be computed, and it is small for moderate distances from the photosphere relatively to R, the solar radius; $(1+\eta) = 1.004547$; the term $(1+\alpha\theta)$ is relatively small within the sun's gaseous atmosphere, since T at the surface of the photosphere is 7535°, at the top of the chromosphere 7479°, at the distance of the outer edge of the inner corona, 35″ arc, 7206° using the gradient temperature fall; and 7003°, 6981°, 6878° for these points computed on the STEFAN formula; or 4952°, 4936°, 4864° computed for a small black spherical body at these places. Compare Table 16, columns 6, 7, 10. We shall not commit a serious error in neglecting $(1+\alpha\theta)$ through a range of 200° or 300° at most, especially since the coefficient of expansion, which for hydrogen is 0.00367 at terrestrial temperatures, must be much smaller at solar temperatures, though I am unable to assign a value to it. The remaining term $\log \frac{B_o}{B}=\frac{h-h_o}{K}$ involves only the height and the barometric constant K. Since $K=\frac{l}{M}=\frac{\sigma_m B_n}{\sigma_h M}=\frac{RT}{M}=7{,}296{,}570$ meters, it is evident that the diminution of the pressure with the height is very rapid. If we assume that the pressure in the reversing layer, or at the surface of the photosphere, is 5 atmospheres,* as given by the spectrum shift of the lines under pressure, we compute that the pressure vanishes to a practical vacuum at the height of 35″, which is twice the diameter of the earth or about the top of the inner corona.

Table 15 contains the computation of the relative intensity at different distances from the sun, counting that at the earth equal to unity; the total emission at these distances, when $J_o=4.0$, the solar constant at the upper surface of the earth's atmosphere; the effective temperature of a plane surface, and also of a spherical body. Table 16 gives a summary of the temperatures and the pressures at different selected distances:

6″.0 = top of the chromosphere.
17″.5 = a distance equal to the diameter of the earth.
35″.0 = the top of the inner corona.
350″.0 = the average extension of the outer corona.
398″.0 = the point where $\varphi=45°$.
480″.0 = ½ radius of the sun.
700″.0 = the limit of the highest prominences.

The temperature difference Δt is computed for the height h with the gradient $-0.0129562°$ C. per kilometer. The temperature T is from STEFAN's formula $J_o=\sigma T^4$; the total intensity is from $J_o=\pi q \sin^2 \varphi$; the relative intensity $=\frac{\sin^2 \varphi_1}{\sin^2 \varphi_2}$; and T_1 is obtained from J_o by the factor ¼ as indicated above. The second section of the Table 17 gives the pressure at these elevations, where $B_o=5$ atmospheres at the reversing layer, which is practically on the surface of the photosphere. It falls to 1.265 atmospheres at the top of the chromosphere, and to a vacuum at the limits of the inner corona. These facts must have an important meaning in our interpretation of solar physics.

Chart 19 exhibits the result of the computation of the effective temperatures of a plane surface and of a spherical body exposed to the solar radiation at different distances. These are marked on a line drawn through the center of the circle. The black circle represents the photosphere, the first red circle the chromosphere, and the second red circle the limit of the inner corona. The ordinates are the absolute temperatures T, and the abscissas the distance from the center of the sun, where $R=960″$, and $d=$ the distance from the surface. At the surface temperature 7535° the gradient temperature is applied such as would occur in the solar hydrogen atmosphere. The curvature of the STEFAN curve as it approaches its limit 7003° does not and ought not to coincide with the temperature as computed from the gradient. It is not unnatural to assume that the law of solar atmospheric absorption may be such as would be found on joining these two lines by a smooth curve as indicated by the dotted lines, since it is not probable that either of these laws continues independently of the other from the surface of the sun to distant portions of space. It may be true that we have not arrived at a perfect solution of these solar meteorological problems; but it is quite likely that they represent such an approximate approach

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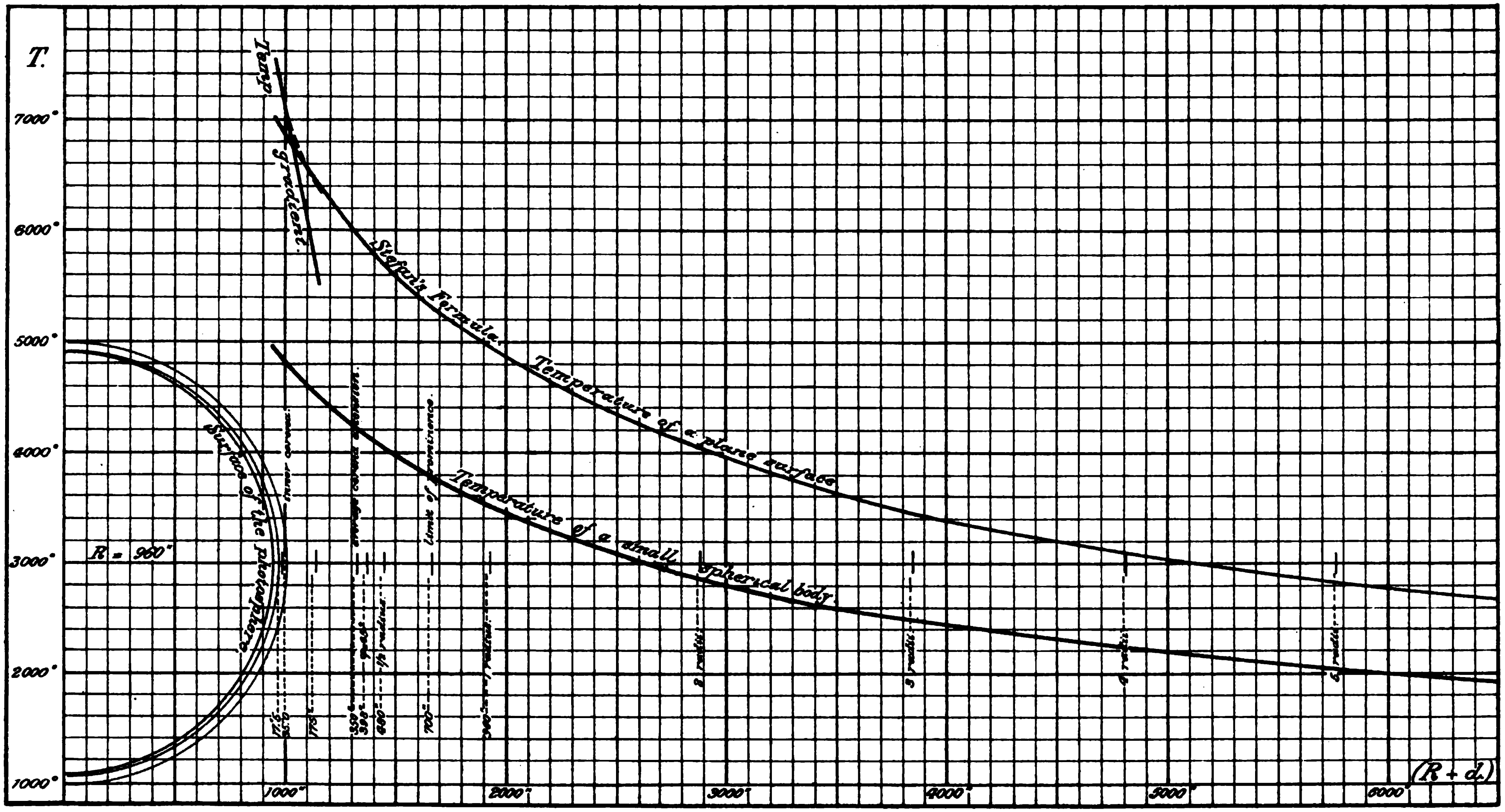
* Note on the pressure of the reversing layer of the solar atmosphere, by L. E. Jewell, J. F. Mohler, and W. J. Humpherys, Astrophysics, February, 1896, page 139. Theoretical considerations respecting the dependence of wave length on pressure, by J. Wilsing, Astrophysics, May, 1898, page 327. Absolute wave lengths, etc., by L. E. Jewell, Astrophysics, April, 1900, page 240.

CHART 19. The temperatures of a plane surface and of a small, black spherical body at different distances from the surface of the sun.



to the truth as will enable us to judge accurately of the value of certain statements which have been published regarding these phenomena.

REMARKS ON THE COMPUTATIONS BY VON OPPOLZER AND FENYI.

We note that since $\left(\frac{dt}{dh}\right)_e=9.869°$ C. per 1,000 meters at the earth, and $\left(\frac{dt}{dh}\right)_s=0.0129562°$ C. per 1,000 meters at the sun, and because, $g_s=g_o\times 27.6=g_o\,.\,n$, the force of gravity at the sun is 27.6 times that at the earth, we have $\left(\frac{dt}{dh}\right)_s=\left(\frac{dt}{dh}\right)_e\cdot\frac{1}{n^2}$. The first n is involved in $g_s=g_o\,.\,n$, and the second in $B_s=B_n\,.\,n$, for computing $\left(\frac{dt}{dh}\right)_s=\frac{1}{(P_o)_s}$. By the formula $\log\frac{B_o}{B}=\frac{h-h_o}{K}$, on computing K, the n appears once in $B_s=B_n\,.\,n$. We have,

$$\frac{dp}{p}=-\frac{n}{RT}\cdot dh \qquad \text{and}$$

$$\log\frac{p_o}{p}=-\frac{n}{RT}\cdot h,$$

where $h_o=0$ on the surface of the photosphere.

Also, since

$$\frac{dt}{T}=\frac{k-1}{k}\cdot\frac{dp}{p},$$

$$\frac{dt}{T}=-\frac{k-1}{k}\cdot\frac{n}{RT}\cdot dh$$

$$\frac{dt}{dh}=-\frac{k-1}{k}\cdot\frac{n}{R}=-\frac{1}{\varepsilon_p}\cdot\frac{n}{R}=-\frac{1}{\varepsilon_p}\cdot\frac{nT}{T}=-\frac{n}{P_o}.$$

In these formulæ,

$$n=\frac{1}{\left((1+\alpha t)\,(1+\beta)\,(1+\gamma)\,(1+\frac{h+h_o}{R}\right)}$$

Von Oppolzer, in his computation of the solar vertical temperature gradient (Astrophysics, October, 1893, p. 738), uses $n=27.6$, $\frac{k-1}{k}=\frac{1}{3.4615}$, $R=420.552$, and finds $\frac{dt}{dh}=18.96$ per 1,000 meters, which is 1463.4 times as large as my value given above. The difference comes from neglecting to evaluate the full value of n in the temperature and the gravity terms. For 1″ arc=720.860 kilometers, this gives a range of temperature 13667°, which is an impossible result, and renders invalid the accompanying discussion.

Fenyi computes the pressure fall with the height (Astrophysics, June, 1896, p. 24) by the formula, $\frac{p_o}{p}=e^{\frac{nh}{RT}}$, or $\log\frac{p_o}{p}=\frac{Mn}{RT}\cdot h=\frac{h}{K}$. However, he interprets this n as the ratio $\frac{g_s}{g_o}$, whereas the true value is that given above, and it is the variation within the solar atmosphere itself: his ratio has already gone into the construction of K. Hence, Fenyi's values of p differ somewhat from those given in Table 16.

THE ELECTRIC AND MAGNETIC FORCES IN THE SUN.

The pressure is about one-fourth as much at the top as at the bottom of the chromosphere; at a height equal to 17″.5 the diameter of a spherical volume the size of the earth it is one fifty-fourth as much; at the height of 35″ it has practically vanished, and at the height of 175″, to which prominences frequently attain, it is quite inappreciable. We may conclude that at the height of the chromosphere the pressure is diminished to one-fourth that of the photosphere, and at the outer boundary of the inner corona it becomes negligible. Beyond the inner corona the space is practically without gas pressure and is really a vacuum; the prominences therefore extend into this vacuum, though their bases rest within the region of low pressure. It is noted that the lower strata of the prominences contain metallic substances as recorded by the spectral lines, but that the higher parts show features much more characteristic of rarefied atmospheres charged with electric forces. Especially the spectrum of the hydrogen lines calls for electric action on the rarefied masses; the rapid motions in the line of sight also suggest electric repulsions between adjacent masses of charged particles. The illumination of charged particles by the radiation of the sun is adapted to produce fluorescence with a spectrum composed of continuous and fluted bands, also single bright lines. The investigation of the fluorescence of sodium and potassium vapors by WIEDEMANN and SCHMIDT (Astrophysics, March, 1896, p. 211) is pertinent to these remarks. It is here stated that our purpose is now to introduce electric discharge forces as an important agent in producing the solar phenomena above the chromosphere.

We have seen (Table 16) that the temperature fall is 9°.4 for the first 1″; 56°.4 to the top of the chromosphere, leaving it about 7479° if that of the photosphere is 7535°; 164° to the height equal to the diameter of the earth, and 329.2° to about the top of the inner corona, outside of which the temperature diminishes by STEFAN'S law. We are led to consider whether there are to be found evidences of a cathodic radiation, a fluorescent radiation, and a radio-active radiation which may be properly ascribed to this particular region; and on this basis we proceed to discuss the constitution of the outer corona. The above results seem to be much more probable than those of VON OPPOLZER or of FENYI, and if they are correct, we see the way for further computations depending on these values. The upper strata of the solar atmosphere, occupying generally the region of the inner corona, are under conditions favorable for producing the phenomenon of gaseous ionization. They are rarefied to a suitable degree, are under temperatures fit for violent molecular and atomic agitations, and if, as has been assumed, powerful electric discharges take place in the solar material, then the atomic masses themselves are disintegrated, negative ions are detached, and as carriers of electricity they are propelled out into space by electric repulsion to form the outer solar corona. This view locates the electric currents in the heated gases of the inner corona, which are good conductors of electricity under low pressures, and admits the doctrine of gaseous ionization with the production of cathodic or negative carriers of electricity, or corpuscles of matter. At the same time we also hold that the solar nucleus is viscous or quasi-solid, that it is the seat of magnetization, and that the lines of force emitted by a spherical magnet can be traced in the structure of the outer solar corona. If these two systems of force exist simultaneously, a magnetic field in the nucleus, and an electrostatic field with electric discharges and ionization in the outer portions of the spherical envelope, then their interaction must produce a configuration corresponding to this physical formation. For it is well known that the negative ions are deflected from their linear path by a magnetic field, and also by an electrostatic field, as explained in J. J. THOMSON'S papers. If m=mass, ϵ=the electric charge, H=magnetic field, ρ=radius of curvature, Q=quantity of electrification, W=heat energy, F=electrostatic field, θ=the deflection produced by F, and l=distance, then $\frac{m}{e}=\frac{H^2\rho^2 Q}{2W}=\frac{H^2 l}{F\theta}$.

THE EXPERIMENTAL DATA.

But we seek now a general theory rather than a special discussion of the corona, and so proceed to experimental data. It will be remembered that my investigation of the polar rays of the solar corona was based on measured positions of points (r. θ) upon the clearly distinguishable curved lines, visible in the eclipse photographs of July 29, 1878, January 1, 1889, and December 22, 1889. These are all eclipses of minimum solar activity, and are suitable for studying the polar structure of the sun, while the coronas of maximum activity show only a confused or structureless configuration about the entire periphery. These measures were discussed on the hypothesis that the polar curves are in effect magnetic lines of force seen in projection, and therefore distorted except on those rays springing from the visible edge of the disk of the sun. The work was described in the American Journal of Science, November, 1890; July, 1891; Astronomical Society Pacific, No. 14, 1891; No. 16, 1891; The Solar Corona, Smithsonian Institution, 1889; Bulletin No. 21, United States Weather Bureau, Solar and Terrestrial Magnetism. The outcome was to show that these rays conform closely to the theory, but the special point of importance to note is that the bases of the polar rays are confined to a belt about 10° wide whose central line is 32° from the poles of the sun. *In other words, the polar regions are denuded of* *visible lines of force through an arc of 50°, 25° on each side the pole, and then the rays spring up thickly in a sort of collar or ruffle quite like the distribution of the terrestrial aurora.* This fact is so important that the tabular results are here reproduced. Table 18 gives in the several quadrants of the three coronas the number of rays measured in each, and the reduction back to the invisible base of the ray for the several measured points ($r . \theta$) where r is the radial and θ the angular distance of the point. The majority of the rays seem to spring within 5° of the same polar distance, namely, 32°, and no rays were located near the poles. It was easy from these data to construct a small model showing the polar ruffle. The axis of the northern and the southern polar crowns is not an exact diameter of the sun, but the coronal poles are about 5° from the sun's axis of rotation, and the southern precedes the northern by about 100°. The resulting model is

TABLE 18.—*Computed polar distance of the base of the visible rays of three coronas.*

Corona of July 29, 1878. [Quadrants of rays.]				Corona of January 1, 1889. [Quadrants of rays.]				Corona of December 22, 1889. [Quadrants of rays.]			
NE	NW	SW	SE	NE	NW	SW	SE	NE	NW	SW	SE
° '	° '	° '	° '	° '	° '	° '	° '	° '	° '	° '	° '
1 30.40	1 33.5	1 35.0	1 31.41	1 37.36	1 30.22	1 32.8	1 31.44	1 33.16	1 28.33	1 30.50	1 31.35
28.35	30.17	31.41	33.25	33.46	31.28	32.39	32.40	30.22	29.27	32.21	31.30
2 28.32	30.2	30.21	29.28	33.20	29.49	30.42	31.11	27.35	28.33	30.33	31.26
3 28.43	2 28.2	2 29.22	2 30.28	2 27.19	2 30.1	2 31.1	2 27.47	2 25.31	2 25.7	2 28.9	2 32.4
32.55	27.41	31.23	32.34	29.44	30.34	29.0	27.4	25.42	24.58	27.12	33.39
30.59	26.11	30.44	3 34.25	28.18	27.59	29.27	27.17	25.27	25.28	26.37	30.4
4 31.8	3 36.30	3 33.59	34.59	3 24.45	3 32.7	3 31.29	3 29.56	3 30.33	3 29.0	3 28.14	3 61.46
33.39	34.5	32.26	31.48	24.28	33.1	32.16	30.14	31.9	29.0	28.11	31.53
30.32	32.5	30.50	4 33.45	24.45	31.7	30.53	29.51	29.57	28.59	28.18	31.24
5 32.41	4 34.52	4 30.17	34.1	4 18.38	4 32.7	4 30.27	4 32.24	4 27.25	4 26.0	4 26.56	4 31.16
33.17	33.30	31.25	31.38	17.51	33.48	30.41	33.8	27.32	25.59	27.15	31.19
31.32	32.26	30.14	5 34.1	17.35	31.0	29.25	31.17	26.41	26.4	26.46	31.6
6 33.25	5 34.24	5 33.51	34.19	5 31.17	5 33.7	5 34.27	5 33.23	5 30.15	5 34.1	5 28.58	5 32 35
33.18	35.0	35.51	33.25	30.53	34.31	35.10	33.55	30.12	34.22	29.2	32.48
34.34	34.23	33.20	6 34.52	31.29	31.57	33.26	32.46	30.17	33.24	29.31	31.19
7 36.0	33.5	6 36.33	34.54	6 38.0	6 34.14	6 29.25	6 33.24	6 31.38	6 34.13	6 34.33	6 33.4
36.23	31.29	36.35	32.38	38.25	34.36	29.29	34.50	31.42	34.32	34.50	33.31
35.16	6 41.55	35.41	7 35.8	37.3	33.33	29.5	33.10	31 9	33.40	33.52	32.12
8 42.25	41.58	7 38.59	35.13	7 43.11	31.17	7 37.49	7 34.53	7 31.28	7 34.23	7 36.40	30.33
42.23	40.49	38.57	35.11	43.5	30.4	35.53	35.31	31.39	34.31	36.38	7 33.56
40.16		8 41.6	8 39.7	42.17		36.28	32.55	31.1	34.1	36.34	33.41
		41.7	39.11			8 42.55	8 37.49	8 28.42	8 38.22	8 37.34	32.29
		40.30	38.39			43.11	37.17	28.37	38.43	37.55	
			37.25			42.2	35.30	28.48	37.37	37.25	
								9 35.59	9 39.39	36.5	
								36.0	39.40		
								35.47	38.33		
								10 38.7			
								38.24			
								37.31			
33.41	33.36	31.21	34.16	31.8	31.50	33.19	32.35	30.57	32.6	31.38	32.3
33°.59'				32°.13'				31°.41'			

therefore somewhat unsymmetrical to the axis of rotation, and it was shown that by rotating the model through a certain angular distance, corresponding to the computed period and the adopted epoch, the location of the measured and computed coronal poles for at least three eclipses agreed too closely to be a coincidence. It will soon be shown that a similar procedure enabled me to forecast the corona of May 28, 1900, with success. The eclipses formed at a time which is distant from the minimum are not favorable for a close verification of such predictions. It may be remarked in passing, that SCHAEBERLE's mechanical theory of the solar corona adopts the view that the polar regions are cleared of coronal rays, but my model differs from his in this respect, that on the mechanical theory the streamers are orbital paths of projectiles thrown out near the sun-spot belts, so that his model locates the bases of the rays in latitudes 20° to 30°, while mine are placed in latitudes 50° to 60°. I have not been able to find that the visible rays are located as near the equator as the sun-spot belts, but in fact it is evident that the rays seen on the edge of the disk, in the so-called synclinals, are not based in such low latitudes. In consequence of several doubtful physical assumptions employed by him, we can not accept SCHAEBERLE'S interpretation of the data shown by the eclipse photographs.

PUPIN'S AND EBERT'S EXPERIMENTS.

It is evident that one step is yet lacking to complete this chain of argument. The discovery of the ionization of rarefied gases under numerous physical conditions, such as the radiation of ultra violet light, oscillating discharges of high tension, and so on, has put us in possession at last of an explanation of the result of my investigation of the structure of the corona which has been lacking, and for want of which the theory was without an experimental verification of its existence. The fact, however, that magnetic rays repel ionized carriers of electric charges requires exactly the effect that was found in my coronal research. If the nucleus emits a strong magnetic field whose axis is near that of the axis of rotation, the repulsion of the magnetic lines of force upon the electric charges will drive the electric rays out of the polar regions, and concentrate them in a ruffle or crown at a distance depending upon the relative strength of the magnetic and the electric forces. A proof of this fact is to be found in an experiment performed by H. EBERT, which is quoted in this connection. PUPIN'S coronoidal discharges, which are well known, have attracted favorable opinion by the similarity which is shown in several particulars between the appearance of the electric discharges through poor vacuua and those shown by the coronal structure of the sun. PUPIN'S experiment dealt exclusively with discharges from a central conducting sphere to the walls of a spherical shell surrounding it, whose surface was covered with a conducting material. It is evident that this apparatus produces vacuum-tube discharge, and that cathodic rays are produced by it in abundance. However, it is not yet strictly applicable to our theory of the sun, because it does not have a directive magnetic field superposed upon the electrical discharge. PUPIN'S phenomenon is really a disorganized kind of general radiation, more like that seen during the times of maximum solar activity, but we require to have this unregulated structure organized into a typical form, namely, that of the magnetic field surrounding a spherical magnet, and this is to be done by superposing a magnetic field upon an electric discharge field with its cathode rays in a poor vacuum. I quote EBERT'S description of his experiment:*

THE ELECTROMAGNETIC THEORY OF THE POLAR-LIGHT PHENOMENA AND THE SOLAR CORONA.—H. EBERT, KEIL.

For the explanation of the most important characteristics of the polar-light phenomena the following experiments were made: Spheres, disks, and cylinders of iron and brass were exposed to the *action of electromagnetic oscillations* in spaces filled with rarefied gases; by this means their surroundings glowed, and the bodies mentioned were clothed with envelopes of light having a ray-structure, whose color and appearance was different according to the nature of the gas. *If these rays were then subjected to the lines of force of a strong magnetic field* the following phenomena were seen:

(1) If the magnetic lines extended through the rarefied region they illuminated the basal portions of the rays of light. If these disappeared, as when the gas was made too rarefied, they also appeared again when the field was strengthened.

(2) The rays of light are strongest in a field of medium strength.

(3) They follow the direction of the magnetic lines of force.

(4) When the lines of force are very dense and impinge at right angles to the surface of the iron body, *the rays of light are thrust to one side. The polar collar of the magnetized iron sphere, for example, was entirely robbed of rays; the light structure surrounds the pole in the form of a ruffle, the inner boundary of which follows the same direction as the lines of force.*

These experiments illustrate the following characteristic peculiarities of the polar light, when one assumes that the sun radiates to the magnetized earth those electromagnetic waves of which only the shortest are directly cognizable to us, that is the light and heat waves:

(1) The polar light builds itself in the thinned higher strata of our atmosphere, especially where the intensity of the terrestial magnetic field is sufficient for illumination under the action of the electromagnetic radiation, that is in the polar regions. Only in times of high solar activity does the phenomenon show more frequently and extend also into lower latitudes.

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* Versammlung deutscher Naturforscher u. Ärzte, zu Lubeck, 1895.

(2) The rays of the polar-light corona follow the lines of the magnetic force.

(3) The frequency of the polar light increases toward the magnetic pole; in the neighborhood of the pole itself where the lines of force enter and emerge in the greatest numbers nearly at right angles, they fail again.

(4) The polar light stands over a zone of greatest frequency in the form of a more or less concentric light ruffle, so that when one passes over this zone on our hemisphere, the polar lightss hine no more in the north but in the southern horizon.

The phenomena just mentioned ought to find an application in the explanation of the solar corona. In many appearances of the corona (as, for instance, in the one recently examined of January 1, 1889) numerous rays of light extend out from the polar regions of the sun, which bend toward the equatorial regions just like the lines of force of a magnetized sphere such as the earth. How the axis of the sun lies we do not know exactly, yet it can hardly be open to doubt that it also sends out lines of magnetic force into space. Among these at times of electromagnetic excitations in the interior of the sun (period of activity) the finely divided particles must in the neighborhood succeed in lighting up to considerable distances. Then the phenomenon shown in the corona comes to existence.

DEDUCTIONS FROM EBERT'S EXPERIMENT.

The experiment of **Ebert** forms such a fitting proof of the denuding of the polar regions of the sun as to establish a whole train of results upon a probable if not firm basis. Also, the entire subject of the interaction of magnetic lines of force with electrically charged minute carriers or corpuscles in the form of rays, has been so far developed in the last three years as to supply another missing link to the analogue, and to strengthen the magnetic theory of the solar corona. This mutual action between magnetic and electric lines becomes, then, the key to the solution of the entire range of solar and terrestrial phenomena whose explanation has so long eluded the efforts of scientists. The theory is an old one that the sun is a magnetic body and that the corona is formed by electric discharges. But so many difficulties have been thrown in the way of accepting this hypothesis from the theoretical side, and the argument that the sun must be a gaseous body on account of its average low density and high temperature, and therefore can not be the seat of even quasi permanent magnetization, have weighed so strongly with many physicists as to exclude the magnetic theory from their consideration. However, such names as the following can be quoted in favor of something of the kind, with more or less definiteness of statement: **Marchand**, **Veeder**, **Pupin**, **Corrigan**, **Meldrum**, **Terby**, **Ranyard**, **Maunder**, **Sidgraves**, **Ricco**, **Ellis**, **Faye**, **Wilsing**, **Ebert**, **Rowland**, **Poincare**, **Dolbear**, **Huggins**, and others. If the above facts as narrated are accepted as indications of the solar constitution, then we are led to the following premises for future work, and the tentative views of these scientists are placed on a fairly satisfactory basis.

1. The solar structure consists essentially of a nucleus and a distant concentric shell.
2. The nucleus is quasi solid, and it is sufficiently magnetized to emit a strong magnetic field which extends into distant interplanetary space.
3. The concentric shell is the seat of electro-magnetic radiations caused by electric oscillations of electric charges on the atoms. It is the seat of the division of certain atoms into ions which are charged with electricity and stream out from the sun along the electrostatic lines of force. It is the seat, also, of X-ray, fluorescent, and radio-active phenomena. The combination of these radiations with the dust-like particles of matter in the neighborhood of the sun produce the continuous and band spectrum and the fine lines of the corona.
4. The interaction of the magnetic field with the electric-discharge field gives the corona the special forms observed in eclipses. At the minimum activity the polar regions are robbed of rays and the equatorial extensions are most developed; at maximum the balance between these forces seems to be changed so that the electric forces of the shell predominate, together with the irregular forms of the corona.
5. The maximum of the eleven-year periodicity would seem to indicate a strengthening of the electric superficial system, in consequence of an increase of the radiations from the interior; the magnetic field also intensifies at the same time, while the balance of forces, acting on the atoms, which brings about visibility is altered so as to produce the characteristic effects observed in eclipses.
6. The system of magnetic and electric causes and effects thus outlined is such as to give the solar meteorology of cloudy condensation, and the irregular effects due to anomalous refraction

and dispension their proper proportion, so that there is no more cause for confusion regarding them than in the analogous case of the earth's atmospheric electricity and the formation of clouds.

7. If the polar regions of the sun are rich in magnetic rays and the equatorial in electric rays, and these two systems interact by a delicate balance of adjustment to produce visible coronal light, then their interaction in the 11-year period may also account for the quadrantal shape of the corona seen in the middle parts of the period. For if the electric rays consist of charged particles of the same sign, as negative in cathode rays, the mutual repulsion among the particles will produce a fan-like spreading of the lines in proportion to the distance from the surface in the direction of the ecliptic. Such trumpet-shaped extensions are frequently observed in the coronal field as well as in a vacuum tube. Hence, there are magnetic rays curved from the poles toward the equator, and electric rays curved from the equator toward the poles. These opposite curvatures operating against each other seem to be able to produce the lance-shaped forms of the corona seen in middle latitudes, so that the entire structure should seem to have a quadrantal synclinal formation at the middle portions of the period. This interplay of the curvature of the magnetic and electric fields, if correctly analyzed, is capable of affording specific data regarding the relative strength of these two fields of force, and thence progress can be made in the correlated problems of solar physics.

CORROBORATIVE EVIDENCE REGARDING THE MAGNETIZATION OF THE SUN.

(1) THE CORONA OF MAY 28, 1900.

There are yet other lines of development which in view of the position thus assumed have an increased degree of importance, and I shall briefly illustrate and summarize the results of several extensive researches in this direction.

The rotation period of the sun has been sought in many ways, but the results are in conflict with each other, so that the decision as to the final value is still withheld. From an extensive computation on the variations of the terrestrial magnetic field I arrived at the solar period 26.679 days, and computed the ephemeris from the epoch June 13.72, 1887. The best way of meeting the objections based upon theoretical considerations as to the truth of this solar period is to put it practically at work, and thus test its efficiency. This period was therefore employed to rotate the coronal model of the sun mentioned above, by applying the ephemeris and setting the model in the position assigned by the computation at the time of several eclipses. The verification depends chiefly upon the coronas observed at minimum, because the confusion of the ray structure does not permit a sufficiently close identification of the poles of the coronal streamers at other times. These poles were found to be about 5° from the axis of rotation, the south pole preceding the north by about 106°. This asymmetry between the axes of the coronal and the solar poles when seen from different points of view, as from several points in the earth's orbit, is a phenomenon easy to verify. The planes of the coronal poles were fixed by a selection of the central lines of the polar-ray structure as given by the photographs, and then these polar lines were plotted upon the well-known astronomical diagram of the projection of the poles of the ecliptic, sun and earth. By the same computation as that shown on page 138, Bulletin No. 21, Weather Bureau, the position of the model for May 28, 1900, was found to be as follows:

Computation of the longitude of the coronal poles for the eclipse of May 28, 1900.

Date of the eclipse G. M. T	May 28^d 2^h 57^m
" " " "	May 28^d.12
Next preceding epoch of the ephemeris (epoch June 13.72, 1887—period 26.67928 days)	May 18.96
Interval elapsed, in days	9^d.16
" " in degrees	135.1
Longitude of the sun	66.7
Reduction to heliocentric longitude	180.0
Approximate heliocentric longitude of the south coronal pole	21.8
Approximate heliocentric longitude of the north coronal pole, being 106° behind the south pole	275.8
Heliocentric longitude of the earth at the eclipse	246.7

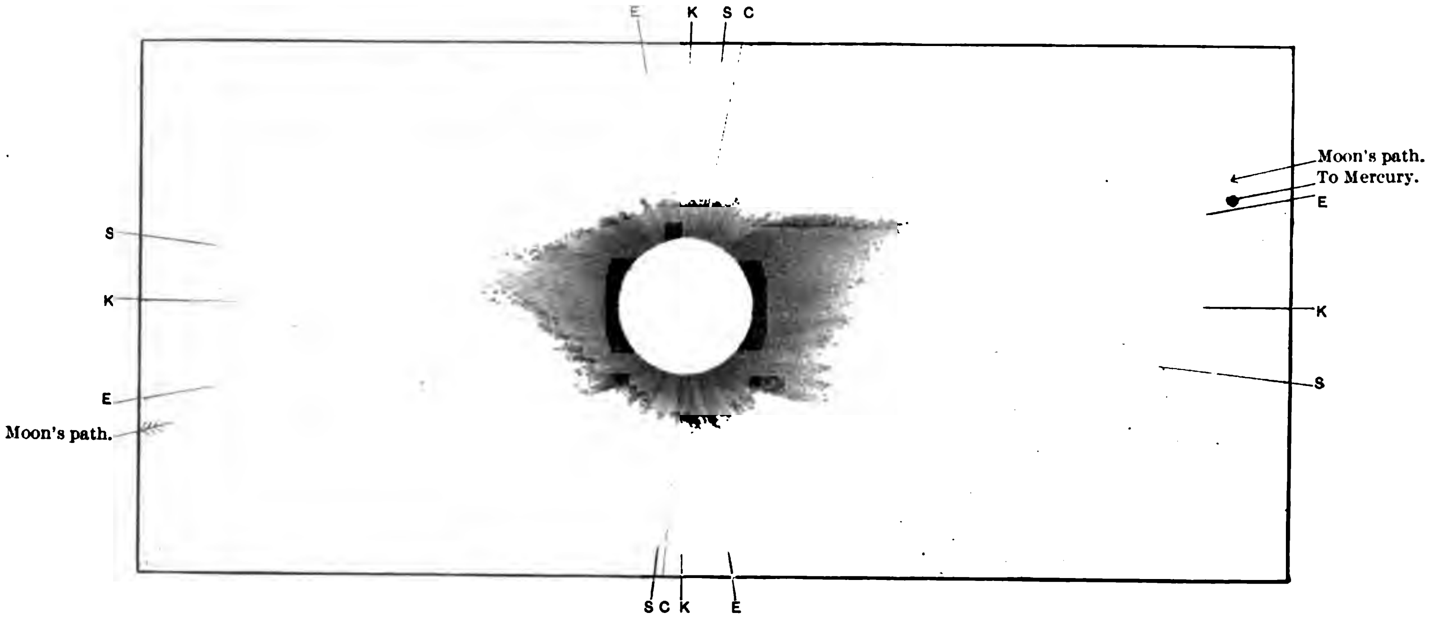

CHART 21.—FROM MR. L. E. JEWELL'S DRAWING OF THE CORONA OF MAY 28, 1900.

The north coronal pole is in heliocentric longitude 276°, while the earth itself is in longitude 247°, so that the pole C is to be seen a little to the right of S on the northern side of the disk; at the same time the southern pole C is in longitude 22°, and is to be seen about halfway between S and K on the southern side of the disk. The model thus set was photographed, and the skeleton rays about the polar regions, which show the orientation of the corona, were filled in by assuming the type of structure for the coronal extension corresponding to a minimum of the eleven-year period. This diagram was published in the *Popular Science Monthly*, May, 1900, page 9. The legend east-west was accidentally interchanged in reproducing; it does not agree with the original drawing, and it is obviously inconsistent with the system of axes, E. K. S. Chart 20 gives a reproduction of my original drawing, and it should be compared with Chart 21, which is a copy of L. E. JEWELL's drawing of the corona of May 28, 1900. His drawing is a carefully executed study of the coronal pictures obtained by the parties of the United States Naval Observatory at Wadesboro, N. C., and at Barnesville, Ga., and it gives the details of the corona with much distinctness. Mr. JEWELL was kind enough to lend me his original drawing to use in this connection. It was also published in Astrophysics, July, 1900. A comparison of JEWELL's drawing with the one prepared by Mr. W. H. WESLEY,* from photographs taken by members of the British Astronomical Association, shows that they agree very closely even in many details. I have marked the poles of the ecliptic K, of the sun S, of the earth E, and their respective planes. The planet Mercury appears on the extreme right of the plate; the moon's path is drawn on the picture. The special feature of interest in this connection is the position of the poles of the corona C. C, which have been prolonged to the edge of the disk. They are seen to agree as closely as possible with the central polar rays as determined by the general balance of the system. It is noted that the axes C. C are not in the same diameter, but make a considerable angle with one another at the center of the disk. They are, in fact, both on the same side of the solar axis S. S. This divergence, however, matches the central positions of the polar ray structure, which would not be the case unless these magnetic poles were inclined to each other. This asymmetry of the coronal polar rays has been a persistent feature of the various coronas heretofore examined, and the unusual characteristics of this figure are repeatedly satisfied by the successive coronas from 1878 to 1900, as far as the photographs permit their examination. The probabilities are very small that this sort of coincidence occurring after many rotations of the sun can be an accident.

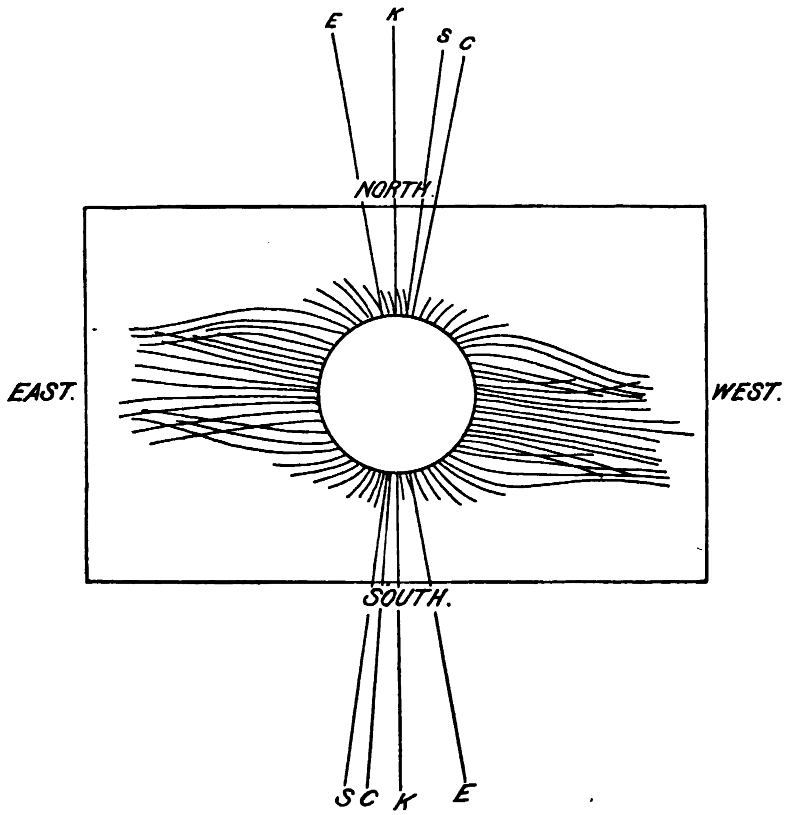

CHART 20.—BIGELOW'S forecast of the corona of May 28, 1900.
E=earth's axis; K=axis of ecliptic; S=axis of sun; C. C=poles of the solar corona.
Original F. H. B. KOE=9° 45'. KOS=7° 11'.

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*The Total Solar Eclipse, May 28, 1900, edited by E. Walter Maunder, F. R. A. S.

(2) THE RELATION OF C AND C′ IN FOUR CORONAS.

On Chart 22 are seen the relative positions of the poles, *K*=eclipse, *E*=earth, *S*=sun, *C*=corona at the four eclipses, July 29, 1878, January 1, 1889, December 22, 1889, and May 28, 1900. The heavy line drawn inside the arc of the outer circle, which is employed simply to magnify the diagram and marked *C*, represents the position of the coronal axes as projected from the model located by computation from the ephemeris; the outer heavy line, marked *C′*, indicates the position of the coronal axes as determined from the photograph. The position of the axes *C′ C′* can easily be verified, but it must be done carefully by measures under a suitably mounted microscope, and these must include the entire polar region as well as the adjacent coronal rifts. If the poles of the corona rotate with the same angular velocity as that of the photosphere at the equator it means that this is the angular velocity of the nucleus, and that the photosphere drifts over the nucleus in middle latitudes with a velocity determined by the forces which control the circulation in the sun, just as the atmosphere drifts over the earth's surface with variable angular velocities in different latitudes. For our present purpose it is sufficient to note that the repeated agreement of the two positions of the coronal poles, *C* computed and *C′* observed, is rapidly taking the 26.68 day period out of the list of tentative data. Every such coincidence occurring after a large number of revolutions of the sun have intervened renders it very unlikely that chance has given these results, and, according to the theory of probabilities, becomes strong evidence in favor of the truth of the period itself.

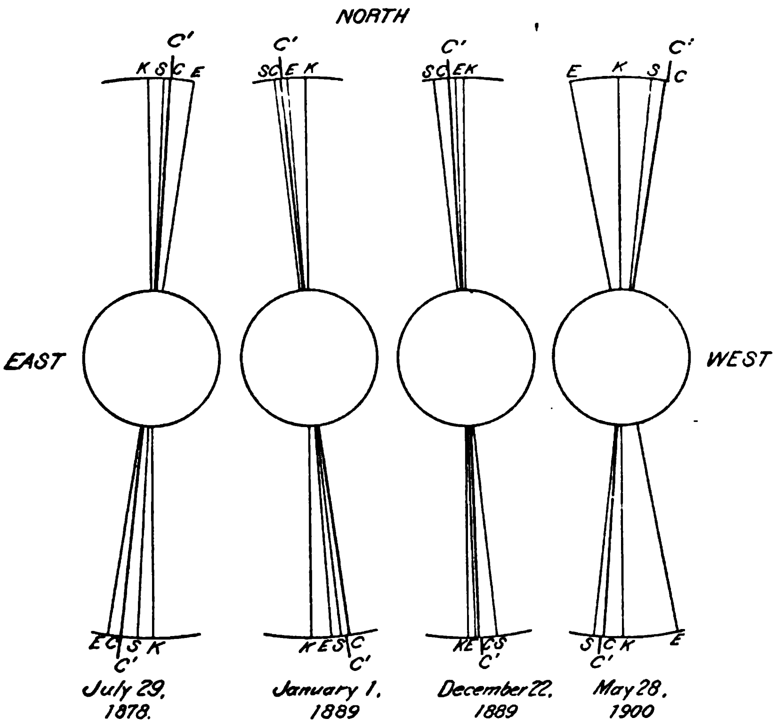

CHART 22.—Computed position of the coronal pole *C*.
Observed position of the coronal pole *C′*.

3. THE SUN-SPOT AREAS.

The sun-spot areas, when the available observations were reduced to a homogeneous system, were collectod in the 26.68-day period, so that a relative number corresponding to the size of the spotted area on the central meridian of the sun was entered in a tabulation for the interval of time, 1854–1891, with the following result. The two hemispheres were collected separately, and the sums for each day of the period, with their variations on the mean sum, are given in Table 19. These variations are plotted in the second and fourth curves of Chart 23. It was found that similar curves are developed, having the same number of maxima and minima, in the northern and the southern hemispheres, but the curves as a whole, both in general inflection and in the ordering of the crests, are the inverse of each other. This indicates that for some reason the spotted areas on the sun have an excess or a defect, varying from the average in solar longitude, and that some meridians are therefore more prolific than others. This would seem to suggest that a sort of structural nature must exist in the nucleus from whence the spots proceed, such that there is a distinct variation of activity at certain places in longitude. Furthermore, on the same meridians these curves are complementary, which would indicate that the northern and the southern hemispheres, respectively, alternate in activity in the same longitude. This curious result naturally suggests some interaction of positive and negative magnetic and electric forces on the sun, but I can not explain what it is. The variation is vigorous enough to produce residuals as large as 25 or 30 per cent of the average total activity. In accordance with the internal convection of the sun by means of vortices perpendicular to the plane of the equator, it is probable that this alternate formation on successive meridians must be referred to some fundamental law of cooling in large radiating bodies, but this requires investigation.

TABLE 19.—*The sun-spot areas distributed in the 26.68-day period.*

NORTHERN HEMISPHERE.

1854–1891.

	Sum	Variation		Sum	Variation
1	1602	− 49	16	1718	+ 67
2	1373	−278	17	1483	−168
3	1518	−133	18	1937	+286
4	2001	+350	19	1519	−132
5	1581	− 70	20	1384	−267
6	1643	− 8	21	1734	+ 83
7	1729	+ 78	22	1617	− 34
8	2007	+356	23	1561	− 90
9	1617	− 34	24	1826	+175
10	1960	−309	25	1685	+ 34
11	1753	+102	26	1733	+ 82
12	1734	+ 83	27	1526	−125
13	1354	−297	Mean	1651	
14	1187	−464			
15	1794	+143			

SOUTHERN HEMISPHERE.

1854–1891.

	Sum	Variation		Sum	Variation
1	1307	−384	16	1628	− 63
2	1613	− 78	17	1783	+ 92
3	1567	−124	18	1556	−135
4	1865	+174	19	1887	+196
5	1458	−233	20	2017	+326
6	1563	−128	21	1903	+212
7	1887	+196	22	2161	+470
8	1650	− 41	23	1836	+145
9	1175	−516	24	1818	+127
10	1395	−296	25	1645	− 46
11	1145	−546	26	2190	+499
12	1493	−198	27	1308	−383
13	1750	+ 59	Mean	1691	
14	1779	+ 88			
15	2271	+580			

The evidence regarding the formation of sun spots and the allied phenomena is that the sun operates through a series of outbursts, irregular outputs of force, flushes of heat, discharges of magnetic polar force, and intensifications of electric currents in the heated atmosphere. This is apparently inherent in the constitution of the sun, however it may be explained. These curves do not represent fixed and rigid conditions, maxima and minima of permanent potentials arranged in harmonic series of a high order. Also, unless the sun were a homogeneous, smooth, magnetic sphere, symmetrically balanced about its axis, its rotation necessarily would produce variations in the distant magnetic and electric fields of force in contact with it. Prof. A. SCHUSTER, in his paper, "On the possible effects of solar magnetization on the periodic variations of terrestrial magnetism," Phil. Mag., October, 1898, page 395, treats the case of a uniform homogeneously magnetized sphere,

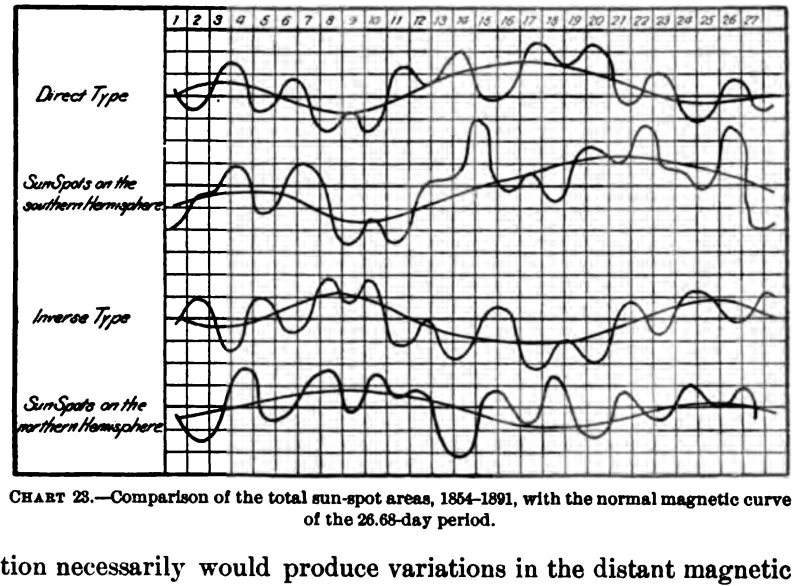

CHART 23.—Comparison of the total sun-spot areas, 1854-1891, with the normal magnetic curve of the 26.68-day period.

and allows for more complicated forms of magnetization by component additions of secondary potentials, but this is always a *steady* distribution. He draws the inference that the existence of a synodic period is excluded, by reason of the relative movement of the earth's axis along the orbit, and also states that the period has no *vera-causa.* But it is evident that the supposition of a fixed potential system is not applicable to the sun, which is essentially a self-active and spasmodic source of energy. The theorems which follow on the assumption of a fixed magnet, rotating in the position of the sun, do not fulfill the actual conditions so as to make the results wholly comparable. The interaction of two permanent spherical fields, as of the sun and the earth, would give certain periodic terms, but the actual sun does not provide these premises. The problem of the effect of a variable system of outbursts in a central sphere has never been solved, and at present the only thing to do is to tabulate the effects without presuppositions as to the result, for the sake of deriving data upon which to found a solution.

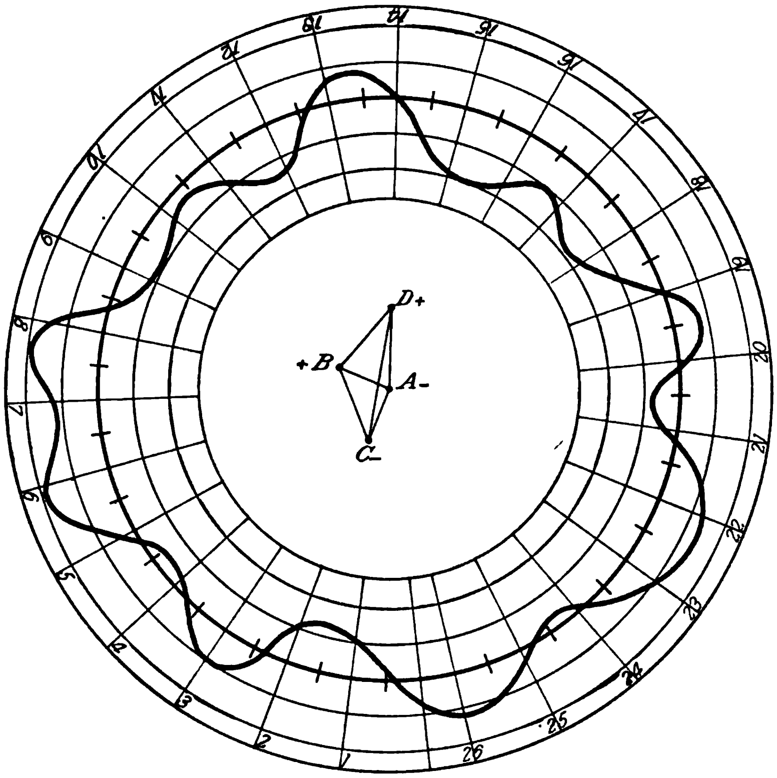

CHART 24.—Direct type of the variation of the magnetic and meteorological elements in the 26.68-day period.
Epoch—June 13.72, 1887. Period 26.67928 days.

With this end in view, I have laboriously arranged the terrestrial magnetic field in the 26.68-day period, and find the curves reproduced in the first and third on Chart 23. The similarity between these terrestrial and solar curves is striking, but the inference has been carefully avoided that the solar distribution of spots is the cause of the terrestrial effects. On the other hand, a different explanation of the cause of this inversion phenomenon in the terrestrial field has been worked out in Bulletin No. 21, and appears to be in accordance with the facts of the case. It may be stated, in passing, that the terrestrial inversion is entirely different from the solar, the latter being a local distribution on the surface of the sun, while the terrestrial is an orbital effect producing semiannual inversions. The type curves have been traced back to 1841 in the terrestrial magnetic field; they reappear in the atmospheric pressures and temperatures of the northwestern portions of the United States with considerable distinctness, and show that the solar activity registers itself not only in the sun's atmosphere, but in that of the earth as well. The northwestern portions of the American Continent are the regions where the cyclones of the northern hemisphere chiefly generate, while the European Continent is the place for their dissipation. This renders the former a specially sensitive place for registering the extra-terrestrial forces; on the other hand, European meteorology deals only with decaying atmospheric structures, and is not adapted to the detection and study of these forces.

(4) THE POLAR ORIGIN OF THE DIRECT TYPE CURVE.

If the direct type of our typical curve be wrapped about a pole as on Chart 24, it produces a certain configuration, which is the effect of having superposed upon a mean magnetic field a series of impulses, assumed to be due to the variable internal magnetization of the sun, which is in turn correlated with changes in pressure, temperature, and electric conductivity in the gases of the solar atmosphere. It is not a stationary curve to be discussed rigidly by the potential theorems. If this curve be examined for centers of activity, by assigning positive and negative poles to proper points, it is found that the curve can be constructed approximately by magnetic interaction from the four points *A B C D*, where the angle *B A C* is equal to 106°. If *A* is the south and *B* the north magnetic pole, then by adding two subordinate poles *C* and *D*, we have *B*. and *D* positive, *A* and *C* negative. The Siberian pole in the northern hemisphere and the indistinct Pacific pole in the southern hemisphere of the earth furnish a suggestive analogue, as to the probability of a large magnetized globe possessing minor centers of action in addition to that of the principal axis. Drawing lines extended through the pairs of pole points, and perpendiculars from each pole upon these lines in all simple directions, counting the density of the rays and drawing a proportional intensity curve, we have one quite similar to that of the Chart 24. There is no intention to claim great accuracy for such a construction, yet the conformity of the drawing to the type curve is such as to show that the sun may have four centers of magnetic action. Hence, any theorem based upon a single axis of magnetization is to be regarded as incomplete till this agreement, furnished by the long series of terrestrial magnetic observations already computed, is disposed of in some other way. For these two reasons (1) that the sun does not appear to have a steady magnetization, and (2) that the observations seem to indicate more than a single axis of magnetization, it is proper to withhold assent to the result deduced from the potential theorems, because they ignore these circumstances and are therefore imperfect or inapplicable. If the direct observations produce a synodic period at the earth, and if this period proves to be efficient in terrestrial magnetism and meteorology, as it does, we may utilize it until a complete theory and a full understanding of the physical laws involved are acquired.

Professor **Schuster** discusses the results of several investigations into the solar rotation and its influence on the earth's magnetism, by means of his theory of "hidden periodicities," using the *declinations* of the Greenwich Observatory for the years 1871–1895.*

Table of results (Schuster).

Period, in days	Intensity or square of amplitude	κ=ratio of the intensity to the expectancy
25.87	0.001001	0.95
25.929	.001027	0.93
26.68	.000242	0.23
25.809	.006168	5.86
25.825	.004182	4.07
26.181	.001144	1.09
26.255	.001081	1.04
26.814	.005936	5.64
27.061	.002943	2.80

It should be observed that "there is a remarkable unanimity in the smallness of the value κ, showing that the amplitudes are even less than the average amplitude calculated on the theory of chance." Also it may be noted that there is about the same probability for the periods 25.809 and 26.814. Of course, both of these can not be simultaneously correct, and either the method of discussion fails or else there must be some explanation of the general failure of any one of this group of periods to conform to the Greenwich observations. The latter is probably the fact. The irregularities in the earth's magnetic field are so great and erratic that it is hardly possible to obtain clear evidence of the true periodic action from any *single* station. It is usually sufficient to take the mean daily values of the components for *five* stations before submitting them to the discussion, but it is not surprising that the records from the Greenwich Declinations alone should have proved insufficient.

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*The periodogram of magnetic declination, as obtained from the records of the Greenwich Observatory during the years 1871–1895. Cambridge Phil. Trans., vol. 18, pp. 107–135, 2 plates.

Furthermore, it is plain that the disturbing vectors in space have three rectangular components referred to the terrestrial magnetic meridians, namely, horizontal or S—N, declination or E—W, and vertical or Nadir-Zenith, and it is therefore an *incomplete procedure to use only one component*, as was done in this discussion. Here it is clearly imperfect, because, as shown by my own computations and by those of VAN BEMMELEN, there is *no true* W—E *component, since the disturbing vectors lie on or very close to the magnetic meridians.* This, of course, refers to the successive means of the 24 hourly observations, or the system of vectors acting from day to day, which eliminates the diurnal variation in longitude. By the theory that the earth lies in an external magnetic field sustained by the sun, the direction of the field at the earth is nearly parallel to the axis of the earth's own field, and there should be no W—E component. The theory and the observations agree that there is no true persistent component which disturbs the declination. Now, Professor SCHUSTER'S discussion comes to this same result, and therefore it sustains the theory. Evidently at most his result is merely competent to declare that the E—W component is wanting, but it is not proper to infer from this fact that the horizontal and the vertical components will fail to disclose a solar period, and it can lead to no such conclusion regarding them. Had the discussion been based upon the horizontal or the vertical components or the resultant of them, that being the proper basis for such a work, the result would not be open to this objection.

EKHOLM and ARRHENIUS have sought to find the period of the rotation of the sun by discussing the variations of the aurora* and thunderstorms. Somewhat the same difficulty pertains to this class of material, namely, that it is very discontinuous, and complicated with other transformations in the atmosphere. A single outburst of the auroral intensity will sometimes outweigh the total amount perceived in many days of ordinary activity. It is like trying to discover the period by using the strong magnetic disturbances in place of the continuous traces of the magnetograms. In short, the numerous divergent periods which have been obtained reflect unfavorably either upon the choice of material adopted for discussion, or upon the fact that a mere tabular compilation does not suitably eliminate the other component forces inherent in the crude observations. Thus, thunderstorms are developed only after the solar energy has accumulated and culminated, after drifting eastward in the circulating motion of the lower strata of the atmosphere, and they do not directly measure the time of the solar impulse. In fact, therefore, we infer that the horizontal and vertical magnetic components are more fit to be discussed for a solar period. So many periods are derived having about 26 days in length, that this raises a suspicion that in some way the true solar period is mixed with other components, and that the combination gives such a resultant. From all the data available, one solar rotation takes about 26.7 days at the equator and at the poles, and about 27.3 days in the midst of the sun-spot belt. But it is very difficult to conceive how a period of 26 days—that is, one having a quicker rotation by 1 part in 27—can be derived from the sun in its rotation taken alone by itself. Since thunderstorms and aurora are associated with the materials of the earth's atmosphere, and these drift eastward rapidly over our northern stations, it is evident a component due to the relative drift of the atmosphere over the station of observation must be subtracted from any observed recurrence of events at the station in order to leave the purely solar period. In my opinion this entire subject needs a more careful and thoroughgoing treatment than it has yet received from meteorologists and physicists, and then it is quite likely that many apparent difficulties will take care of themselves and disappear. I desire to state that the phenomenon of inversion which I have described is not accidental, but that it persists in magnetic and meteorological phenomenon. It is quite possible that my explanation of its cause may be imperfect, but that is no argument against the facts adduced in evidence of its existence.

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* Ueber die nahezu-26-tägige Periode der Polarlichter und Gewitter, von Nils Ekholm und Svante Arrhenius.

THE NATURE OF THE CORONAL LIGHT.

We shall now attempt to go a little more closely into the nature of the coronal light. There are three theories before us for consideration: (1) The incandescent theory and dissociation of the elements; (2) the ionization of the solar gases producing as products the electrically charged carriers which are torn from the atoms; and (3) the X-rays as electrical impulses, or pure but minute electromagnetic waves. It is quite probable that the coronal light in reality contains all of these sources of light in mixture, because in the solar atmosphere conditions are favorable for producing each one of them. It is the duty of observers to try to apportion their relative amounts. The coronal light shows a continuous spectrum and polarization, indicating that there are minute solid masses in an incandescent state which also reflect the solar light; there are some fine bright lines present, and some students believe that helium and coronium are the dissociated products of hydrogen. The difficulty with the theory of the reflected or scattered light is that the dark **Fraunhofer** lines corresponding with the light of the photosphere have not been found in the corona. Explanations have been offered of this fact, and special efforts are being made to detect the dark lines in eclipse observations. Much depends upon the result. Furthermore, the previous description of the curvature of the polar and equatorial rays shows that besides the dust particles just mentioned, a large percentage of the total number of rays are composed of electric charges carried upon even finer particles of matter, which are ionized rather than chemical products of dissociation. Also, it may be assumed that the collision of these charged ions with neighboring molecules or molar masses should, by the shock of the impact, detach the electric charge in the form of electromagnetic impulses, as is possible in accordance with the views explained in the papers by **Heaviside**, J. J. **Thomson**, and others.*

We quote a few sentences from J. J. **Thomson**:

> Under the action of the magnetic field the narrow beam of cathode rays spreads out into a broad fan-shaped luminosity in the gas, which is equivalent to a magnetic spectrum. As the cathode rays (1) carry a charge of negative electricity, (2) are deflected by an electrostatic force as if they were negatively electrified, (3) and are acted on by a magnetic force in just the way in which it would act upon a negatively electrified body moving along the path of these rays, I can see no escape from the conclusion that they are charges of negative electricity carried by particles of matter. (Phil. Mag., Oct., 1897.)

It is now understood that these particles of matter are very small portions of the ordinary atoms torn apart physically, but not chemically dissociated, by powerful electric discharges. Again,

> If these particles be suddenly stopped, there will, in consequence of electromagnetic induction, be no instantaneous change in the magnetic field; the induction gives rise to a magnetic field which, for a moment, compensates for that destroyed by the stopping of the particle. The new field thus introduced moves off through the dielectric as an electric pulse. When the ratio of the velocity of the moving particle to that of light is nearly unity, two pulses are started when it is stopped: (1) A thin plane sheet, whose thickness is equal to the diameter of the charged particle, and it is propagated in the direction in which the particle is moving; (2) a spherical pulse spreading out in all directions, whose thickness is equal to the diameter of the charged particle, and thus very small compared with the wave length of light. The X-rays are assumed to be these thin pulses of electric and magnetic disturbances which are started when the small negative particles which constitute the cathode rays are stopped. If they are so thin that the time taken by them to pass over a molecule of a substance was small compared with the time of vibration of a molecule, there would be no refraction, and the thinness of the pulse would also account for the absence of diffraction. (Phil. Mag., Feb., 1898.)

The marks of the electromagnetic waves are: Reflexion, rectilinear propagation, polarization, with the magnetic diplacement in the plane of polarization and the electric displacement at right angles to it; refraction, double refraction, interference and diffraction, dispersion, with velocity of propagation dependent upon the inductivity and permeability of the medium. Those of the X-rays are: Apparent absence of regular reflexion and polarization, of refraction and diffraction, and of dispersion; the velocities are less than those of light; they are probably electromagnetic pulses, and not longitudinal or transverse waves of short length; they cause all bodies, whether conductors or dielectrics, to be conductors of electricity; they discharge electrified bodies, those which are opaque rapidly, and those which are transparent slowly; they are transmitted through bodies having carbon, hydrogen, and oxygen elements, while these absorb heat; they form secondary types of radiation when they strike on fluorescent and other radio-active bodies; they increase the number of nuclei in the formation of cloudy condensation; they are not found in ordinary sunlight; they appear mixed with cathode rays in a vacuum tube. But especially the X-rays differ from electromagnetic waves in that they possess a much greater power of penetrating opaque bodies, *and in that they can not be deflected by a magnet.* The same is true regarding their relation to the cathode rays, which penetrate opaque bodies only slightly, and can be deflected by a magnet. **Roiti** asserts that the X-rays are mixed with cathode rays, but can not be separated by simple subtraction, rather by the deflection of a magnetic field. **Trowbridge** finds that X-rays are produced at all points of a continuous conductor inclosed in a vacuum tube where a steady, not oscillating discharge, current of very high pressure through a large resistance is maintained in it. He infers that the X-ray phenomena, produced by a steady battery current, *strongly suggest an electrical theory of the origin of the sun's corona.* (Phil. Mag., July & Sept., 1900.)

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*J. J. Thomson, Phil. Mag., July, 1889; O. Heaviside, Phil. Mag. (5), XXXIX, 1889; W. B. Morton, Phil. Mag., June, 1896; J. J. Thomson, Phil. Mag., Feb., 1898.

We remark in this connection that the coronal streamers seem to have more properties in common with the cathode-type of radiation than either of the others. If the phenomenon, above mentioned, of deflection of the rays and the clearing of the sun's polar region of them is admitted, it is decisive against the X-ray theory, and against the electro-magnetic dissociation theory, because neither of these provide for deflection of the rays in a magnetic field. There may be some admixture of these three types of rays, and, if so, careful observation of the corona may apportion the several kinds, because the cathode or ionized rays would often be crossed by the nondeflected rays of the other radiations.

Mr. **Abbot's** report on the Smithsonian expedition's observations at Wadesboro, N. C., on the eclipse of May 28, 1900 (Astro. Phys., July, 1900), gives the following results:

1. The coronal radiation was recognized by the bolometer, and gave at least 5 millimeters deflection over that of the dark moon.
2. The radiation reflected by the earth's atmosphere during the partial phase is vastly more intense than that of the corona.
3. The corona is effectively cooler than the bolometer, and appears, therefore, neither to reflect much light from the sun, nor, chiefly by virtue of a high temperature, to give light of its own, but seems rather to be giving light in a manner not associated with a high temperature, or at least with the preponderance of infra-red rays usual in the spectrum of hot bodies. This involves a rejection of both the eruptive and the meteoric coronal theories. If an investigation of glow electrical discharges in high vacua should be found to yield effects approximating those of the corona, it would seem plausible to adopt this explanation of the coronal light.

The foregoing statement by the Smithsonian observers is readily perceived to be in accord with the views set forth in the preceding pages. If the coronal light consists of electrically charged particles produced by ionization then we may make further inferences. The light is due to the electrical envelope of the atom, which is in vibration, and the heat to the oscillations of the material particles present. The electrical charges seem to reach a definite minimum of inertia, the same that the charges have on electrolytic ions, while the material portions are only one-thousandth part the size of the common atoms; the material substance may even be wholly missing, according to J. J. **Thompson's** idea of discerptible atoms, or **Lamor's** view of disembodied electrons. Hence the light energy is largely retained, while the heat energy is diminished indefinitely, thus agreeing with the fact that the infra-red heat rays are largely diminished in the coronal light. Therefore the incandescent particles in the corona must be very small, or else they must be few in number in the unit volume. **Campbell** found in the Indian eclipse of 1898 that the inner coronal light gives a continuous spectrum with total absence of dark lines. Such facts as these strengthen the view that the coronal radiation is much like the cathode rays of a vacuum tube. Of course the corollary follows that the atmosphere of the sun is the seat of powerful electric discharge currents, and hence that the induction from these and other sources of electricity causes variations in the magnetization of the sun itself, so that the assumption of a fixed magnetization can not be adopted in analytic discussions, without making due allowance for this fact.

THE ZEEMAN EFFECT.

Zeeman remarks in his paper "On the influence of magnetism on the nature of light emitted by a substance" (Phil. Mag., March, 1896):

> It seems very promising to investigate the motion of the ions for various substances, under varying circumstances of temperature and pressure, with varying intensities of magnetization. Further inquiry must also decide as to how far the strong magnetic field, existing, according to some, at the surface of the sun, may change its spectrum.

The **Zeeman** effect has been studied experimentally, and explained theoretically by **Lamor**, **Michelson**, **Cornu**, **Preston**, **Lorentz**, **Voigt**, **Reese**, and others, so that the phenomenon is well understood. (Compare Table 40.) The spectrum line, viewed along a strong magnetic field, is transformed into a doublet on the edge of the widened line, both rays being circularly polarized, while a middle oscillation is invisible because it takes place in the line of sight which is the direction of the lines of force. If viewed across the magnetic field a triplet is seen, the outer lines being plane polarized parallel to the field and the middle line at right angles to it. These lines can be alternately cut out by turning a **Nichol**'s prism parallel or at right angles to the lines of the magnetic field, respectively. It has been found by investigation that the phenomenon in some lines is much more complicated, producing quadruplets and even much higher orders of separation and subdivision. In general the effect has been analytically explained by equations of motion, which assume that the motion of the ion producing the radiations is in an orbit, circular, elliptical, or more complex, and is under a force of attraction drawing the mass of the ion to the center of the molecular system, and also a force of rotation impelling it round the axis of the magnetic line. Since light radiation is made up of ether motions produced by ions rotating in all possible planes and directions, the magnetic field simply assorts or resolves them into right and left hand rotations in planes perpendicular to its lines of force, and into harmonic linear oscillations along its lines. The superposition of the curl motions of the magnetic field upon these motions of the ions accelerates or retards the periods, and then the spectrum grating assorts the resulting vibrations into lines displaced by a certain $\Delta\lambda$ from the original position of λ.

The important points for our present purpose are the facts, that (1) in the ions of gas the charges of electricity are the same as those which occur in the electrolysis of liquids, while the mass of the carriers in gaseous ions is a small fraction, one-thousandth of those in liquids. The evidence points strongly to the disruption of the atomic mass, though it seems incredible to the imagination, but even so our interest is especially concentrated upon the orbital motion of the electric charge and its effects when propagated in electro-magnetic waves of light. The alternate hypothesis to account for the facts is that the ion is a disembodied unit of electricity, called an electron, constant in inertia and able to exist distinct from the ether and from matter itself. This will be a subject of scientific discussion for some time to come, and it involves points of fundamental theoretical importance. (2) The magnetic line of force is shown to be a rotation of the ether about the axis of the line, and it is therefore a vortex in the ether, able to enter into combination with the orbital motions of the ions producing light. (3) This orbital rotation of distinct charges of electricity about the mass of the atom, like a close satellite about its planet, is capable of transforming an atom into a magnet. Professor **Fitzgerald** remarks:

> The ion revolving in its orbit is equivalent to an electric current round the orbit, and therefore the revolving ion and the matter with which it is associated behave as a little magnet having its axis perpendicular to the plane of the orbit.

The subject of electrical charges moving in circular orbits has been worked out by **Heaviside**, J. J. **Thomson**, **Schuster**, and others, so that the subordinate theoretical relations are well known. (Compare Table 37.) **Reese** (Astro. Phys., Sept., 1900) objects that this rotation of an isolated charge is not equivalent to an electric current, on account of the discontinuity in its electro-magnetic impulses. But it is so practically if the frequency amounts to many million rotations per second, and unless the disturbances of the ether by induction do not subside instantly. Furthermore, there has been much discussion regarding the form of the equations to be used in accounting for the complicated forms of the **Zeeman** effect, as shown by the papers mentioned, and **Preston** has even introduced precessional periodic rotations of the plane of the elliptical orbit, a periodic motion of the orbit about the line of apses, and also a periodic motion of the angle of inclination. (Compare Table 39.) This is indeed introducing us into molecular astronomy, with all of its complex perturbations. It seems to me that he is correct in assuming that in addition to the attraction to the center of the mass of the molecule, there should be a mutual attraction between the several atomic constituents of the molecule, as between the planets of a solar system, and that these complex forms of the **Zeeman** lines which are observed must be analyzed on the general principle of celestial astronomy, although the orbits perturbed are of the most minute dimensions.

MAGNETIZATION IN THE SOLAR AND TERRESTRIAL ATMOSPHERES THROUGH IONIZATION.

We obtain an important principle of physics for the interpretation of solar and terrestrial meteorology if we assume that at the source of the light radiations in the sun the atoms must be practically electro-magnets; it is when the electric discharge currents transform the ordinary chemical atoms by ionization into atomic magnets that they are in a condition to emit electro-magnetic radiations through the interplanetary spaces. When this radiation falls upon the earth's atmosphere, a state of ionization is also set up in its atoms, especially in the daytime and throughout the entire depth of it, which converts these atoms into magnets as long as the ionization continues. **Elster** and **Geitel** have already indicated to what a remarkable extent the phenomena of atmospheric electricity are harmonized by the theory of ionization, attributed chiefly to the action of the ultra violet rays. This transitory state of magnetization *in situ*, produced by the electric currents of charged ions is apparently one of the important missing links in our understanding of the system of the physical causes and effects at work in nature.

It will be remembered that in my discussion of the vector system of magnetic deflecting forces operating to produce the diurnal variations of the terrestrial magnetic field, I attributed them not to any system of electric currents operating in the earth's atmosphere, but to a magnetic effect produced by the electro-magnetic field itself. It is true that I had no conception of the phenomenon of ionization when my paper was written, as indeed the subject has been wholly elucidated since that time, and therefore my language was incomplete; but nevertheless it is easily seen that I approached very closely to the seat of the physical process involved. I said:

> The diurnal vector system depends exclusively upon the sun's electro-magnetic or sunlight field, which is a radial field, and apparently induces in the ether an efficient polarization in respect to exploring magnets on the surface of the earth. (Bulletin No. 21, p. 17.)
>
> The immense rapidity of the vibrations of light in the case of a train of waves from the source to the observer practically integrates the system into a type of polarized ether. (p. 34)
>
> The electro-magnetic theory of light implies the existence of a magnetic field practically uniform in force and direction relatively to any magnet large in comparison with the wave length of light, and hence to any magnetic except of atomic and molecular dimensions. (p. 81.)

This was clearly a very close approximation to the more correct statement that the sunlight or electro-magnetic radiations produce ionization in the earth's atmosphere, and that this is accompanied by a subordinate magnetic effect on the individual atoms. In the International Cloud Report, in discussing the diurnal variations of the barometer, after showing the close relations between the diurnal magnetic vectors and the diurnal components of the motions of the atmosphere, and having disapproved the "thermic-manometric process theory" and also the "gravitational tide theory," it is said, the phenomenon is due to the "magnetic attraction" of a field having a certain configuration, depending upon the electro-magnetic radiation (p. 476). This excluded the common theory of electric currents in the atmosphere, the pressure, and the temperature variation theories, and in effect adopted the *ionization-magnetic theory*. We shall return to this topic and discuss it more fully in another connection.

THE EFFECT OF PRESSURE ON LIGHT.

The ZEEMAN effect changes the wave lengths of light by the action of a magnetic field, and the pressure effect shifts the spectrum lines by means of a change in the pressure of the surrounding medium. (Compare Table 40.) The change of period of vibration of luminous molecules or atoms by these two methods should be distinguished from the change of waves which have been emitted through refraction and through the rotation of the plane of polarization in a magnetic field, which is the same as a change in the velocity of propagation of light waves. It is also necessary to bear in mind that there are two theories employed for the explanation of these phenomena, the rivals of one another for the honor of scientific sanction and final adoption, namely, the dynamic and the electromagnetic theories. The former attributes the change of periodic vibration and shifting of the waves in the spectrum to a damping or acceleration of the original periods in which the atoms or molecules as individual masses are moving; the latter to a similar change in the periods of the electrical charges which the atoms carry, rather than to the carrying masses themselves. The ZEEMAN effect seems to be more favorable to the electromagnetic view, and the pressure effect to the dynamic view. Some go so far in ascribing radiation to the vibrations of the electric charges as to subordinate the material mass even to the vanishing point, and thus make the electron the primary thing from which matter is itself constructed; others find in the vibrations of the atomic masses and in the collisions of the molecules sufficient ground for a complete explanation of the facts without any resort to disembodied electrons. These rival schools of thought will no doubt discuss for some time to come the various arguments for and against the adoption of either of these radically different fundamental conceptions. The pressure effect is briefly summarized as follows: A shift in the position of a spectrum line has been found by the experiments of JEWELL, HUMPHREYS, MOHLER, WILSON, and WILSING, to occur, such that it is proportional to the wave length, the difference of pressure, the coefficient of linear expansion of the substance in its solid state, the cube root of the atomic volume, and inversely proportional to the absolute temperature of the melting point; also that there is a proportionality between the principal series and the first and second subordinate series of a group. Hence the shift varies from one element to another, but is not far from 0.010 ÅNGOTRÖM unit per atmosphere, the range extending from very low pressures up to twenty atmospheres by actual experiment. The change in pressure also broadens some lines, either symmetrically or unsymmetrically; it brings out the reversals clearly, but the chief effect in the increase of pressure of the medium, as for example, of air surrounding the electric arc in which the element is rendered incandescent, is to displace or shift the place of the line in the spectrum toward the red end having slower periods. An increase in the temperature increases the number and the intensity of the lines, but does not appreciably shift the lines; an increase in the density or amount of material present in the unit volume increases the width of the lines, either symmetrically or more on one side than the other, but does not seem to shift the lines. A broad line in the solar spectrum is therefore due to the emission of the same element distributed through a great range in elevation in the sun's atmosphere, where the pressure changes considerably. The observed shift of the solar relative to the terrestrial lines indicates that the pressure in the solar reversing layer at the bottom of the chromosphere is about five or six atmospheres, and that it is small near the top of the chromosphere. Irregularities in a line are due chiefly to motions in the line of sight, as distinguished from lines broadened through a wide range of pressure or very variable distributions of the material density. Fine sharp lines tend to be produced nearer the top of the solar atmosphere, and hence, by selecting lines which are emitted at different altitudes, studies can be made upon the relative angular velocities of the different strata, as has been done by DUNER and CREW, though this subject is still incomplete. Since the wave lengths and corresponding positions of lines are related to these several functions it is not possible to determine absolute standards of wave lengths, as MICHELSON proposed to do, unless the conditions of normal waves are definitely prescribed.

It has been shown by v. LOMMEL that a shift of spectrum line is due to change in the wave length, produced by damping the period through superposing an excitant period upon it. His theory depends solely upon the resistance of the medium to the motion of the vibrating atoms.

but Wilsing shows that this damping coefficient and the other dependent terms must be modified so as to include a change in inertia due to the internal friction of the medium upon itself. This theory was first applied by Bessel to pendulum vibrations, and was confirmed theoretically by Stokes. Godfrey points out that the acoustic vibrations of a plate were accounted for by Rayleigh, by superposing a similar subordinate term upon the simple effect of emission of radiation. Also there is an electrical analogue which requires the same kind of treatment. The most important conclusion to be drawn from these facts is that no dissociation hypothesis regarding solar elements is required, but that all the peculiar features in the spectrum lines can be explained by variations of pressure in the sun's atmosphere with the elevation, motion in the line of sight, and changes in the temperature and density of the material. Hence the uprushes and downrushes in the sun's atmosphere, and the motions in the line of sight can all be studied in the spectral lines, as well as the distribution of heat and the materials of the elements, so that finally a quantitative and qualitative scientific knowledge of the sun's constituents will be acquired, and that, too, without resorting to any hypothesis implying unusual or improbable conditions.

THE MAGNETIZATION AND TEMPERATURE OF THE SUN.

The fact that the sun is at a very high temperature seems to many physicists a sufficient reason for concluding that it is not a magnetic sphere. The analogue usually referred to is that of a steel magnet which loses its magnetization when the temperature is raised considerably. On the other hand, the state of the earth would appear to be a more correct analogue, and it is evident that although the interior temperature is excessively high, it yet sustains a magnetic field. The attempt to account for such terrestrial magnetism as exists, through the electro-magnetic induction of currents of electricity in the upper atmosphere, when examined breaks down through the insufficiency of the possible causes of such currents, and the fact that the air is a powerful nonconductor, like the ether, under ordinary conditions, and hence that electric currents are excluded except in very limited regions and under very restricted conditions. There are three possible kinds of electric currents in the atmosphere: (1) The displacement currents due to the readjustment of static potentials of electricity, which in the atmosphere is localized and held apart by pressures up to many millions of volts; (2) the convection currents which may occur by the transportation of electric charges in the movements of the wind circulation, and in the motions of the ions which are produced in special places; and (3) in the conduction currents which occasionally occur, as in lightning flashes when the pressure discharges breaks down the air as a dielectric and temporarily makes it an efficient conductor. Trowbridge (Phil. Mag., August, 1898) finds that the "initial resistance of the air steadily diminishes with the powerful electric stresses, and under disruptive discharge sinks to 2 or 3 ohms." He infers that Edlund's idea of the ether as a conductor of electricity may be true under the conditions where several million volts operate to break it down. (Phil. Mag., May, 1897.) J. J. Thomson in his Recent Researches contends that Edlund's view is disproven on the ground that a vacuum would be opaque, and that no light would be transmitted from the stars through interstellar space. (p. 98.) Sutherland (Phil. Mag., March, 1899) seeks to reconcile this difference of opinion by saying that under moderate electrical pressures the ether and the air are nonconductors, but that under very high pressures with oscillating discharge they may become good conductors, and that this is due to the dissociation of the neutral molecules, atoms, or even electrons, into positive and negative parts, which by ionization produces temporary conductivity. That is to say, in the path of the lightning flash there is intense ionization and corresponding conductivity. This, however, is merely calling by the name conductivity that process which really belongs to the case of convectivity, if the dissociation and ionization theory is realized. Likewise on the sun there must be similar and numerous circumstances producing such temporary conductivity, though on the earth it is confined to few and very transient actions in the lower atmosphere. If this is the case regarding the absence of electrical conductivity in the relatively high barometric pressures and high densities that prevail in the lower parts of the atmosphere, it is found that conductivity also takes place very readily in rarefied gases and at very low pressures. When the pressure is reduced as low as 1 millimeter, more or less, and the molecules are comparatively far apart from each other, it is a common experiment to find that the conductivity is very good when ionization is produced in any way. If the pressure of a gas is reduced gradually to a vacuum, it is found that at a certain minimum pressure the conductivity is a maximum, but that the conductivity decreases rapidly as the pressure is further decreased. This indicates that a given density of the molecules is better for conductivity than a pure vacuum. It is also an argument against the conductivity of pure ether. Hence we infer that only a very thin stratum of air, where the pressure of the atmosphere is about 1 millimeter, is suitable for electrical conductivity, and I do not believe that the magnetic state of the earth is produced by electric currents flowing in this thin stratum.

There are, however, other ways of producing ionization than through the action of the electric discharge current. Thus a gas is rendered more or less conductive (1) by the passage of RÖNTGEN rays through it; (2) by the passage of Uranium and Thorium rays through it; (3) in the neighborhood of a piece of metal heated to redness; (4) near a flame; (5) near an electric arc or spark discharge; (6) near a piece of metal illuminated by ultra violet rays; and generally (7) the passage of solar radiation through the earth's atmosphere or through the sun's atmosphere is believed to be attended by ionization. In all cases the resulting change in conductivity is due to the motion of the ions present. The negative ions move on the average one and one-fourth times as fast as the positive ions, so that if produced simultaneously they tend to separate into positive and negative groups. From this results the increase of potential difference that precedes the lightning flash, followed by a readjustment of the electricity toward equilibrium. It is to be particularly observed that the state of ionization in the atmosphere is set up only in limited spaces, or in small quantities, and that the general statement still holds true that the air is a powerful dielectric and a poor conductor of electricity. The most careful experiments show that air is incapable of receiving a charge of electricity (J. J. THOMSON, Phil. Mag., April, 1890), and that the apparent exceptions are due to the presence of dust or to the appearance of ions. When Lord KELVIN and MAGNUS MACLEAN state (Phil. Mag., August, 1894) that air can be electrified either positively or negatively, because an isolated spherule of pure water electrified either positively or negatively can be wholly evaporated, it is evident that they mean to speak of the fine mixture of aqueous vapor bearing electric charges with dry air in the unsaturated stage, and are not wholly explicit, but they really refer to a type of ionization. We believe that it is quantitatively proven that the air is a nonconductor to currents of electricity traversing large regions of the earth, such as would be necessary to produce the magnetic forces involved in terrestrial magnetism, and that all the theories based upon the assumed conductivity of the air are untenable.

Having examined the conductivity prevailing in cold gases, such as the earth's atmosphere, we may return to the sun, whose atmosphere is very hot, and in consequence favorable to an abundant, if not excessive, ionization, and therefore becomes equivalent practically to a metallic type of conductivity. The physical state of such an atmosphere is very complex, having great kinetic molecular energy or heat, through collisions of high frequency, an abundant development of ionized atoms from the motion of whose electric charges the electromagnetic waves of radiation spread into space, very numerous isolated cathodic charges of electricity subject to deflection in a magnetic field. It is assumed that heat is energy of vibration in the molecular portions of matter; that electromagnetic radiation is an oscillation of the surface electric charges; and that cathode rays are a subordinate type of radiation of charged particles, while the RÖNTGEN, Uranium, Thorium rays, fluorescences, and the still further subordinate radio-active radiations, represent other forms of motion pertaining to the delicate connections existing between the ether and matter. When radiation of any type strikes upon the earth's atmosphere, the most complex phenomena result. This energy is taken up in corresponding molecular motions as heat, or in the ionization of atoms, or in the formation of the more strictly electrostatic charges, or finally in setting up similar subordinate radiations. It seems necessary to distinguish two forms of ionization: (1) That in which the electric charge of the ion circulates in a kind of orbit about the atom and thus converts it into a minute magnet, and (2) the more isolated charges, as in cathodic rays where the light waves are less developed and the motion of the charge is aperiodic, or even anomalous. The photospheric radiation of the sun would seem to be partly of the former type, since its rays appear to be quite subject to magnetic deflection, and partly of the latter type, since there are other coronal streamers extending to enormous distances in space with very little curvature.

One of the leading difficulties in scientific analysis is to distinguish between mathematical fictions and physical realities. There have been numerous instances of the mistaken use of correct mathematical propositions for the explanation of physical phenomena, and this is especially the case before it becomes possible to collect the observations and verify the facts which critically test the theory employed. Because a mathematical theorem might theoretically be applicable to certain conditions in physics, it is unfortunately by no means a proof that this is the true analysis. The history of science indicates how many mathematical fictions have been rejected by the development of better observational data. For example, a spherical magnet having the well-known lines of force surrounding it, may be conceived to be developed (1) by placing a small magnet at the center, (2) by placing two isolated poles near the center, (3) by filling the interior with uniformly magnetized material polarized in one direction, (4) by placing layers of positive and negative magnetism on the surface and distributing it according to the cosine law, (5) by a suitable electric-current system circulating on the surface, (6) by induction from an external magnet, (7) by putting the sphere in an external magnetic field whose sources are distant. Yet, it is necessary to distinguish the facts carefully before, for example, attributing the earth's magnetism to any of these possible causes. In the same way, the magnetism of large masses of matter has been attributed to three different theories: (1) The WEBER-EWING theory, which assumes that each molecule is a small permanent magnet of itself, and that the magnetization is an act of setting all the molecular axes to point one way, which is the polarization of the molecules; (2) the Amperè electric-current theory, which considers that each atom or molecule is surrounded by permanent currents circulating in opposite directions on the two hemispheres, and that they are thus polarized; (3) the ROSING theory (Phil. Mag., Sept., 1896), that matter when magnetized is put into the same motion as the surrounding magnetic field. The connection between ether motion and matter in motion is still obscure, but many physicists have attributed the magnetism of the sun and the earth to their rotation in the ether medium. J. J. THOMSON concludes a discussion of this topic (Phil. Mag., April, 1894) by saying:

> It would appear that if the atoms possess this specific attraction for the two electricities, a large rotating body ought to produce a magnetic field.

Lord KELVIN discusses the action of an "atom" acting on the ether within and around it, according to the idea of attraction and repulsion (Phil. Mag., Aug. and Sept., 1900), and approaches a one-fluid theory of electricity, but identifies the electric fluid with the ether as an elastic solid pervading all space. He says:

> Stress in ether being freed from the impossible task of transmitting both electrostatic and magnetic force is quite competent to perform the simpler duties of transmitting magnetic force alone. If we assume the density of the ether as much as 10^{-6}, I am content at present, however, to suggest $10^{\ 9}$, this, with the velocity of light 300,000 kilometers per second, makes the rigidity (being density times velocity squared) equal to 9×10^{11} dynes per square centimeter, which is somewhat greater than the rigidity of steel, 7×10^{11}. It is clearly not for want of strength that we need question the competence of ether to transmit magnetic force.

This conclusion comes from discussing the motion of an atom through the ether, and shows that the transmission of magnetic force is the immediate result—that is to say, a transmission of velocity of rotation or a magnetic field of force. When the atoms are associated in a large revolving body, similar actions upon the ether set up a magnetic field or polarization throughout the entire mass. The magnetic induction is a kind of motion of ether communicated to matter, and ROSING explains the phenomenon of magnetization as simply a reflexion of tubes of induction from matter. Whatever may be the exact nature of this connection the opinions are certainly gaining ground (1) that the ether is capable of magnetizing a body rotating in it; (2) that the ether is incapable of transmitting electrostatic and magnetic force simultaneously, but is better suited to transmit magnetic force than electrostatic, having less work to do in that type of transmission of energy.

The temperature of a body such as the sun does not primarily enter into this question. Heat is caused by a disorganized motion of molecules in collision, and is a vibration of the substance of matter; electric currents and magnetic rotations, polarized or not, may go on quite independently of such heat operations; if the entire body rotates in the ether, polarizing forces may be generated such as to organize the molecules, so that while executing heat collisions they shall individually hold their magnetic axes parallel to an axis of polarization. It is quite likely that all molecules of matter are magnetic; heat may in many instances disorganize the polarization so that a given mass of the molecules may not appear to be magnetic, but this is not a necessity; and in fact the sun and the earth seem to possess such magnetizations, resulting from their rotations, as to warrant us in assuming that it is not so in their cases. The enormous pressures reducing the matter to viscous density may be also an associate cause tending to facilitate such polarization of the sun. At any rate, enough has been said to show that one has a fair working hypothesis in assuming that the sun is a strong magnetic body, that it is not uniformly magnetized, and that hence a *vera causa* does exist for propagating the variations of its magnetic forces at a great distance from it.

We have thus two true causes for the magnetization of the sun—(1) the convectional vortices of radiation in the interior, and (2) the rotation of the entire mass in the surrounding ether. Both causes no doubt work together and efficiently supplement each other.

THE TRANSMISSION OF ENERGY FROM THE SUN TO THE EARTH.

The evidence from observations on the conductivity of the ether is that it is nonconducting of itself, except when broken down by a powerful electric discharge, or when ionized bodies or other conducting materials are scattered through it. There may be a very minute increase of conductivity in the immediate neighborhood of the sun, but generally the ether is a perfect insulator between the sun and the earth. This point is of importance because of the tendency among physicists to treat cosmical magnetic problems as if the ether were a conducting medium, and the rotation of a body in it were sufficient to induce a system of electric currents of characteristic form. SCHUSTER has shown (Terrest. Mag., Jan., 1896) that any such possible conductivity must be very small, because otherwise the earth's axes of magnetism and rotation would tend to coincide, and the length of the day would be changed by an amount sufficient for the extant astronomical observations to detect. Any conductivity to be derived from interplanetary meteoric matter must evidently be too weak for practical consideration, because of the excessively wide spacial separation between the material portions.

The transmission of energy between the sun and the earth is confined to three possible methods, (1) the electromagnetic radiation, but not including the RÖNTGEN radiation, which does not exist in the sunlight; (2) the electrostatic rays stretching from the sun to the earth in radial lines; (3) the magnetic polar rays which reach the earth along oval paths and depend upon the magnetization of the sun. The electromagnetic radiation, on entering the atmosphere, may cause a small amount of conductivity throughout the atmosphere by the generation of ions, and it is the mode by which most of the energy actually comes from the sun; the ether is a medium which transmits electrostatic stress only at the expense of a very large amount of work, and the potential between the sun and the earth must be enormous beyond any probability to make an effect perceptible at the earth, and we do not believe that it exists; the magnetic polar field readily transmits energy of a certain kind on account of the susceptibility of the ether to take on vortical rotations, though limited to static forms except during temporary adjustments. We will now give our attention to this magnetic field and the testimony of the observations regarding its effects.

As already stated, some students have found in this field an explanation of the remarkable synchronism between the solar and the terrestrial phenomena, as shown in the 11-year solar period and the 27-day period, which has been detected generally in the terrestrial magnetic field and in the several meteorological elements. Lord KELVIN, in his presidential address before the British Association for the Advancement of Science (Nature, December 1, 1892), gave the result of his computation on the work done by the sun in producing a given magnetic storm, and states its amount to be excessive, as follows:

> Thus, in this eight hours of a not very severe magnetic storm, as much work must have been done by the sun in sending magnetic waves out in all directions through space as he actually does in four months of his regular heat and light. This result, it seems to me, is absolutely conclusive against the supposition that terrestrial magnetic storms are due to magnetic action of the sun; or to any kind of dynamical action taking place within the sun, or in connection with hurricanes in his atmosphere, or anywhere near the sun outside. It seems as if we may also be forced to conclude that the supposed connection between magnetic storms and sun spots is unreal, and that the seeming agreement between the periods has been a mere coincidence.

This theory consists in substituting in the equation of energy, $E = -\frac{1}{8\pi}\int\int V \frac{dV}{dn} dS$, the values $V = \frac{m \cos\theta}{R^2}$, and $H = \frac{m}{r_3}$, so that $E = \frac{H^2}{3} \cdot \frac{r^6}{R^3}$, where $H = 0.001$ C. G. S., the magnetic force as observed to vary at the earth, R the solar diameter and r the distance from the sun to the earth. Hence $E = 13 \times 10^{39}$, and the rate of doing work for 50 minutes is 43×10^{36}. (This solution was communicated to me by Professor SCHUSTER.) This theorem and example have been widely quoted, and have carried much weight with them, so that they have acted as a barrier against further investigations on the direct magnetic field of the sun, if not as conclusive evidence against its existence. But before any general theorem of the kind can be accepted it must be shown to be in conformity with the body of observed facts known to prevail in this connection; it should also be shown to exclude all other sources of influence upon the terrestrial magnetic disturbances. Thus it may possibly prove to be the case that there are variations in the quality and even the quantity of the solar radiation, and that the action of this differential source of energy in the ether waves reacts upon the state of the constituents of the atmosphere in the upper regions, and thence to the magnetic field, so that it would not be correct to attribute all the disturbance effect to direct polar magnetism alone. The delicate atomic changes which have been detected in molecular physics make this line of argument not only permissible but also essential. The polar magnetic field working in conjunction with the ionization effects of the electromagnetic field may magnify the magnetic perturbations from some comparatively small quantity to those relatively large values observed during intense magnetic storms, and at the times of the auroral displays. If, as is probable, the aurora is the florescent effect in the argon constituent of the atmosphere, generated by the electric brush discharge following the lines of the magnetic field of the earth, then the superposition upon this effect of the true magnetic solar field may increase the disturbance of the terrestrial magnetic field considerably throughout the strata of the atmosphere. Indeed, we shall indicate that some such atomic action is apparently involved in the production of the diurnal variations of the earth's magnetic field, and that the long-sought cause of this phenomenon will be found in this principle, rather than in the electromagnetic effects of any hypothetical system of electrical currents flowing in the cirrus strata.

But it is not in the incomplete knowledge involved in these conjectural inferences from partially understood physical operations existing in the earth's atmosphere that the real difficulty exists in the way of accepting Lord KELVIN's conclusion. That sort of probable evidence will not become positive till the variability of the solar radiation is established and its complete effect upon the atmospheric ionization fully worked out. The chief obstacle consists in the fact that the view is opposed by an enormous amount of direct observational evidence, persistently accumulating over a long range of time, in all parts of the world, as expressed in the geometrical coordinates of the vectors of the deflecting magnetic forces which are superposed upon the normal terrestrial magnetic field. These results of observation are so well known that very few scientists deny that such synchronism between the solar activity and the terrestrial effect really exists, though there is still difference of opinion as to the way in which this connection between the sun and the earth takes place. As already stated, the primary trouble with assigning to the sun a strong magnetic field has been its high temperature, but, as we have seen, there are decisive evidences of such solar magnetic influence in the lines of the solar corona. The second difficulty has been the amount of the magnetization required to produce the terrestrial effects, but this may be removed by a further study of the effects of the ionized atoms acting upon the magnetic lines which pass through the atmosphere. Finally, as already indicated in the convectional vortex radiation in the interior of the sun, a single vortex tube if located near the axis of rotation may produce a given line of magnetic force outside the sun which can penetrate to the earth. Hence, we need not assume that the entire body of the sun is involved simultaneously in these temporary outbreaks of magnetic force, so that the observed force at any point in space may vary not a little for a while from the mean value of a uniformly magnetized sphere in the place of the sun itself. Thus we can look for disturbances at the earth which do not necessarily involve the entire interplanetary space surrounding the sun up to the same maximum. As confirmatory of the direct magnetic theory we have the following lines of argument, which are here very briefly summarized, but which could be greatly extended in view of the large amount of reliable material derived from the observations already in our possession:

SYNCHRONISM BETWEEN THE SOLAR SURFACE VARIATIONS, THE CHANGES IN THE TERRESTRIAL MAGNETIC FIELD AND THE METEOROLOGICAL ELEMENTS.

(1) In a paper by William Ellis, F. R. S., "On the relation between the diurnal range of magnetic declination and horizontal force and the period of solar spot frequency," in the proceedings of the Royal Society, Volume 63, is given Chart 25, drawn by him from his discussion of the data for the interval 1841 to 1896, inclusive. He says regarding the result:

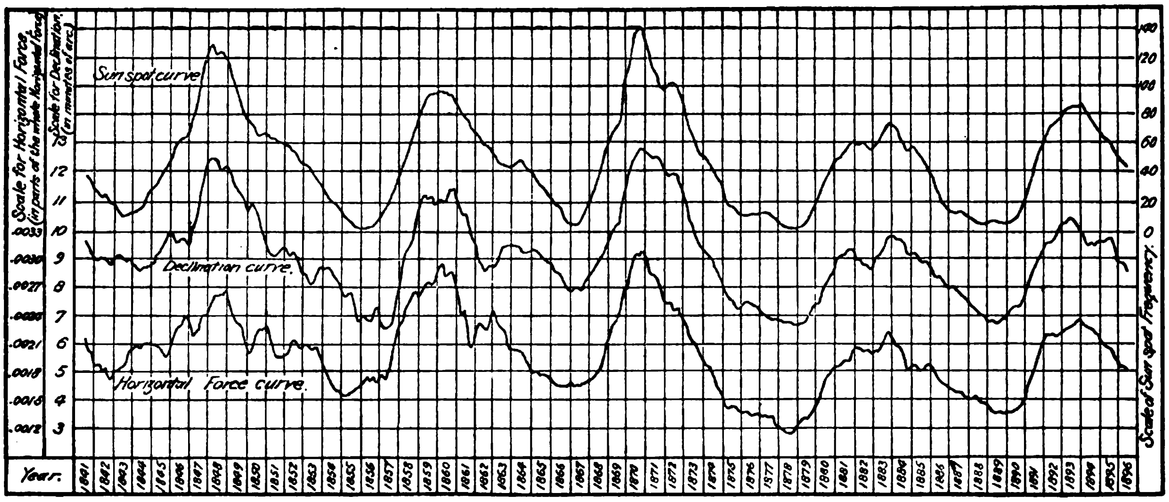


Chart 25.—Smoothed curves of sun spot frequency (Wolf) compared with corresponding curves showing the variation in diurnal range of the magnetic elements of declination and horizontal force, from observations made at the Royal Observatory, Greenwich.

> Considering that the irregularities in the length of the sun-spot period so entirely synchronize with similar irregularities in the magnetic period, and also that the elevation or depression of the maximum points of the sun-spot curve is accompanied by similar elevations and depressions in the two magnetic curves, it would seem, in the face of such evidence, that the supposition that *such agreement is probably only accidental coincidence can scarcely be maintained, and there would appear to be no escape from the conclusion that such close correspondence, both in period and activity, indicates a more or less direct relation between the two phenomena, or otherwise the existence of some common cause producing them.*

A similar result has been reached by all investigators of this subject, both as regards the magnetic field and the frequency of auroras; also in the meteorological elements, the barometric pressure, the temperature, the wind velocity, and precipitation there is the same synchronism.

In order to show how wide the amplitude is from year to year, it was found in the sun-spot cycle 1878–1890 that the following changes took place in the northwestern part of the United States (W. B. Bulletin No. 21, p. 173):

Range in the European magnetic horizontal component,	0.000060 C. G. S.
Range in the external solar coronal field,	0.000180 C. G. S.
Range in the maximum solar (auroral) field,	0.000300 C. G. S.
Range in the northwest (the Dakotas) pressures,	0.10 inch.
Range in the northwest temperatures,	7° F.
Range in the northwest pressure amplitude,	0.06 inch.
Range in the northwest temperature amplitudes,	1° F.

These relations may need modifications whenever the scientific data warrants an improvement, but they serve to show the general connection between the various quantities involved.

It remains to be remarked that if such observational results as these are to be excluded from further consideration by Lord Kelvin's theorem, then there remains little more to be done in this subject, since no other observations seem to be available. However, the same marked synchronism that exists in the 11-year period has been found to extend also most persistently in the 26.68-day period throughout the magnetic and meteorological elements. It has been shown that the periodic curve representing the mean distribution of the sun spots has an inversion in the two solar hemispheres, due to local solar action; also that the solar type curve undergoes a semiannual inversion in the year, due to the generation of opposite types of couples at the earth, in consequence of the changed presentation of its lines to the curves of the solar magnetic field at the distance of the earth's orbit. There may be a further cause for the phenomenon of inversion than the one mentioned, in the disposition of the vortices of radiation within the material of the sun. The inversion occurs at the time of a transition of the earth from one hemisphere of the sun to the other, in the course of its annual orbital motion, and it may be that the positive and negative vertices are arranged in an alternate succession on either side of the sun's equatorial plane, so that the external field has an inverted intensity in longitude, as shown by the curves of Chart 23. Such detailed and characteristic evidence of continuous touch between the solar output and the terrestrial field would seem to prove that the proper procedure is to maintain the general theorem of the direct magnetic action of the sun on the earth till its applicability is demonstrated or the above chain of facts accounted for in another way.

(2) When the variations of the terrestrial magnetic field are examined in detail, it is found that they indicate that forces have been impressed upon it which originate generally in a direction perpendicular to the plane of the orbit, and that they act athwart the normal lines of the earth's field, and therefore originate outside the earth and not inside of its surface. This excludes the view that the perturbations are caused by variations in the magnetized material of the earth, or in the hypothetical system of electric currents in the atmosphere which are assumed by some to produce the magnetism of the earth. This remark does not apply to the terrestrial electric currents which synchronize with them, but are effects in the earth's crust depending upon the preceding variations in the external magnetic field.

(*a*) The curves of Chart 26 illustrate the fact that the entire magnetic field of the earth in both the northern and the southern hemispheres, and in all longitudes, is simultaneously moved by one common impulse, and that the magnetic elements oscillate up and down synchronously in the most irregular pulsations. No meteorological system of air currents in the general or the local circulation exists which can account for the minute oscillations from which the mean curves are constructed, and therefore that source of the variation as a general terrestrial effect is excluded from the discussion, because there are, in fact, no corresponding meteorological oscillations common to the entire earth. The integral effect of numerous impulses in a magnetic field denoting solar activity may on the other hand locally modify currents of circulation having their origin in the well-known temperature gradients. The argument is not here reversible, as some might hastily assume. These curves are traces of the horizontal force as recorded simultaneously in the observatories at Greenwich, Toronto, Singapore, St. Helena, Cape Good Hope, and Hobart. Other stations might be added, but they would all agree, as is well known. It was found by an extensive, careful study of similar groups of curves, divided into periods of 26.68 days, and extending the examination from the year 1841 to the year 1896, that they can be classified into two types, each period conforming more or less closely to the typical curve, and to such an extent that the prevailing curve can usually be specified. These two types, called the direct D and the inverse I, are formed by using the same curve in inverted positions and turning it over on its longer axis, so that one curve is really employed throughout this comparison. By matching the type curve in either the direct or inverted position with each period as marked off by the 26.68-day ephemeris, as shown in the example on Chart 26, it was found that the distribution of the types, given in Table 20, is arranged in a semiannual period which is so related to critical or turning points in the earth's orbit, as concerns the position of the sun's axis, that the relation can not be accidental. The facts here assigned are entirely independent of any explanation of the cosmical cause of them, and even should the theory which I have advanced to account for them be superseded, the result will always have importance in this subject. It may be stated that for many years I have followed this semiannual inversion systematically at about fifty stations in the northwestern portions of the United States, by plotting the daily pressures and the temperatures in seven separate groups so that they form continuous lines. There is no doubt in my mind that the period and the inversion exist, and that as a means of studying the laws of the long range weather changes, it is the best that is now available for such purposes.

Synchronism of the variations of the horizontal force throughout the terrestrial magnetic field.

CHART 26.

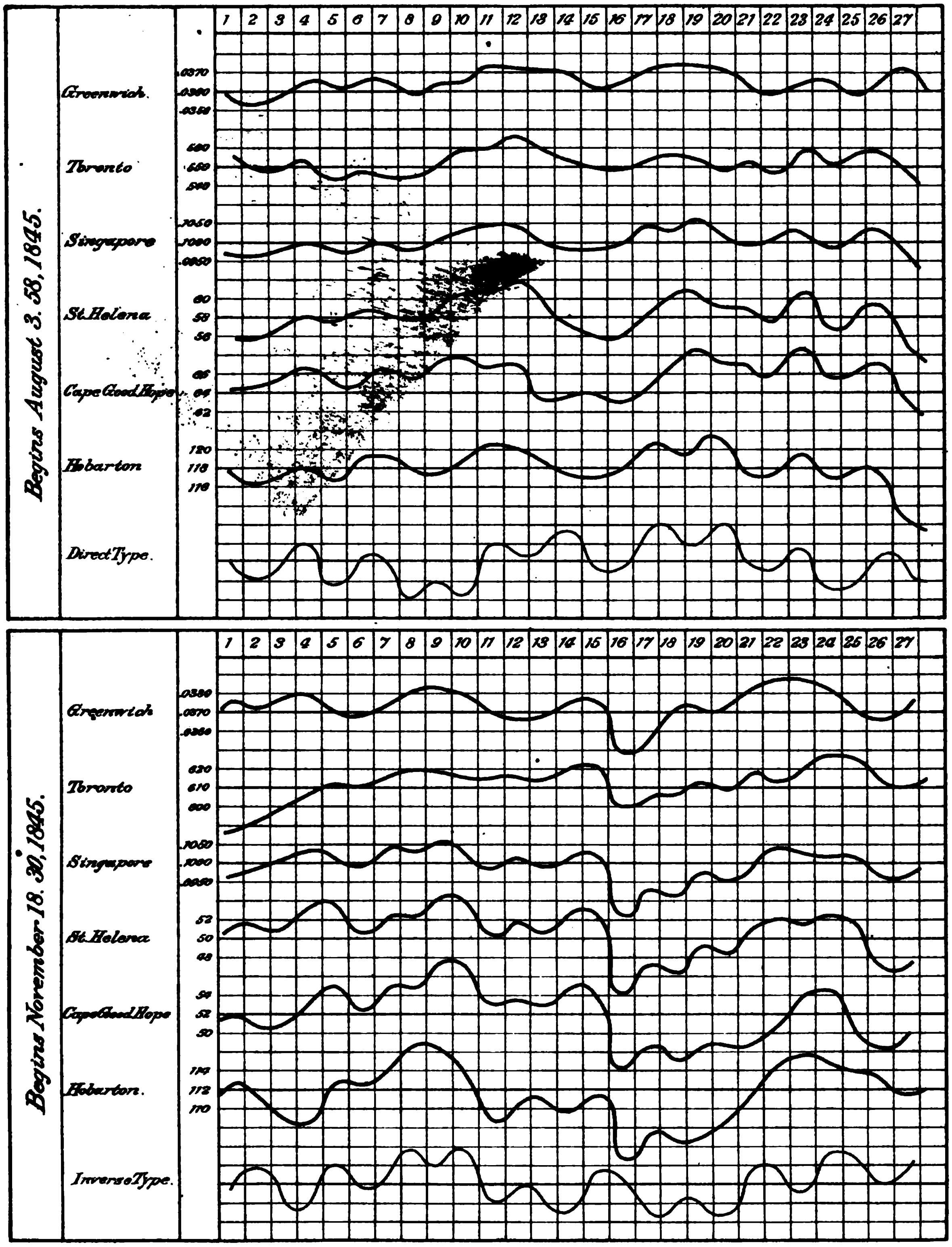


TABLE 20.—*Inversion in a semiannual period of the type recurring in the 26.68-day period.*

DIRECT AND INVERSE TYPES, FOUND BY TRIALS.

JANUARY. JULY. DECEMBER.

Periods	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1841	I	D	D	D	D	I	I	D	D	D	D	D	I	
1842	I	D	D	D	I	I	I	D	D	D	I	I	I	I
1843	I	I	D	D	I	I	I	D	D	D	D	D	I	I
1844	I	I	I	D	D	I	I	D	I	D	D	I	I	
1845	D	D	D	D	I	I	I	I	D	D	D	I	I	I
1846	I	I	D	D	D	D	I	I	D	D	D	D	I	I
1847	I	D	D	D	I	I	I	I	D	D	D	I	I	
1848	I	I	D	I	D	I	I	D	D	D				
1849	I	I	D					D	D	D	I	I	I	I
1850	I	D	D	I	I	I	I	D	D	D	D	I	I	I
1851	I	D	D	D	D	I	I	I	D	D	D	I	I	
1852	I	I	D	D	I	I	I	I	D	D	D	I	I	I
1853	D	D	D	D	I	D	I	D	D	D	D	I	I	I
1854	D	D	D	D	I	I	D	I	D	I	I	I	I	
1855	D	D	D	D	I	I	I	D	D	D	I	I	I	I
1856	I	I	D	D	I	I	D	D	D	D	D	I	I	D
1857	I	I	D	D	D	I	I	I	D	D	D	D	I	
1858	I	I	I	D	I	I	I	I	D	I	D	D	I	D
1859	I	I	I	D	D	I	I	D	D	D	I	I	I	I
1860	I	D	D	D	I	I	D	D	D	I	D	I	I	
1861	D	D	D	D	D	I	I	D	D	D	I	I	I	
1862	I	D	D	D	I	I	I	D	D	D	D	I	I	I
1863	I	I	I	D	D	D	I	I	D	D	I	I	D	I
1864	I	I	D	D	I	I	I	D	D	D	D	I	I	
1865	I	I	D	D	D	I	I	I	D	D	D	I	I	I
1866	I	I	D	D	I	I	I	I	D	D	I	I	I	I
1867	I	D	D	D	I	I	I	I	D	D	D	D	I	
1868	I	I	D	D	D	I	I	I	I	D	D	D	I	I
1869	D	D	D	D	I	I	D	D	D	D	I	I	I	D
1870	I	I	I	D	D	I	I	D	I	D	I	D	I	
1871	I	I	D	D	I	I	I	D	D	D	D	I	I	I
1872	D	D	D	D	D	I	I	D	D	I	D	I	I	I
1873	D	D	D	I	I	I	D	D	D	D	I	I	I	
1874	I	D	D	I	I	I	D	D	D	I	I	D	I	I
1875	D	D	I	D	I	I	I	D	I	D	D	I	I	I
1876	I	D	D	D	I	I	I	D	D	I	I	D	D	I
1877	I	D	D	D	I	I	I	D	D	D	I	I	D	
1878	I	I	I	D	I	I	I	I	D	D	D	I	I	I
1879	I	I	D	D	I	I	D	D	D	D	D	I	I	D
1880	D	D	I	I	D	I	I	I	I	D	I	D	I	
1881	I	D	D	D	D	D	D	I	D	I	I	I	I	I
1882	D	D	D	I	I	I	I	I	D	D	D	I	I	D
1883	D	D	D	I	I	I	D	D	D	D	I	I	I	
1884	D	D	D	D	D	I	I	I	I	I	I	I	D	I
1885	D	D	D	D	I	I	-I	I	I	D	D	D	I	I
1886	D	D	I	D	I	I	I	D	D	D	D	D	I	
1887	I	I	I	I	I	D	D	I	I	I	D	D	D	I
1888	D	D	I	I	I	I	D	D	I	D	D	D	D	I
1889	I	D	D	D	I	D	D	D	D	D	I	I	I	
1890	I	D	I	I	I	I	I	I	D	D	D	I	D	I
1891	I	I	D	I	D	I	I	D	I	I	I	I	I	D
1892	I	D	D	D	I	I	I	D	D	I	I	I	I	I
1893	D	D	D	I	I	D	D	D	I	I	I	D	D	
1894	I	I	D	D	D	I	I	D	D	I	I	I	D	D
D	17	32	42	41	18	7	13	33	43	41	30	16	10	12
25	−8	+7	+17	+16	−7	−18	−12	+8	+18	+16	+5	−9	−15	−13

GENERAL LAW.

	I	D D D Max.	I I I Min.	D D D D Max.	I I I Min.

Tables 21 and 22 contain two examples, taken quite at random from my numerous computations, of the fact that generally the horizontal and vertical components move in opposite directions, and we know that the impulse is quite closely confined to the magnetic meridians. Table 21 gives these components for the disturbance of February 12, 1892, the coordinates having been computed for several selected epochs, chosen for measurement of the deflection of the traces on the photographic registers. While there are many exceptions, the two components have usually opposite signs. The horizontal component is much more reliable than the vertical for two reasons: (1) It is the stronger component in middle latitudes where the stations are located, and (2) the LLOYD balance-magnet does not always behave sensitively and register the external impulse accurately, as can be inferred from the discrepancies existing at neighboring stations which can not be entirely due to the actual stresses in the magnetic field. Table 22 gives an example of the coördinates, not selected for individual minutes, but as the mean values of the twenty-four hourly observations contained in the published reports. It should be noted that the vertical force is less satisfactory than the horizontal for the reasons just given, and that the complete record in both components was not available for all the stations. The horizontal component *dx* shows that there is a synchronous impulse involving the entire earth. The vertical component *dz* is usually of opposite sign to *dx*, if the impulse is pronounced and strong. By taking the sum of the means of *dx* . *dz* in the last column for those days when *dx* . *dz* have opposite signs, we have 1067+358=1425; for the days having like signs, 434+155=589; so that the ratio is about 3 to 1 in favor of the unlike signs. This month was taken as a specimen of the prevailing facts, and is not in itself a very favorable example. There are some days when the magnetic deflecting force is feeble and indecisive, so that the normal field may be conceived as swaying about in an aimless manner. It is on this account that the vertical force is so troublesome, and besides this the observations generally have a tendency to be discordant at neighboring stations.

Since the component *dy* averages very small when the daily means are computed, the *dx* . *dz* impulse is necessarily directed along the meridians; since *dx* . *dz* have in general opposite signs, they can not arise from the same cause that produces the earth's normal field; the direction is easily found by plotting the vectors on the plane of a magnetic meridian, and it is across the normal field, so that the combined vector system developed for the entire earth is evidently part of a magnetic field perpendicular to the plane of the orbit, and, by inference, we refer its source to the sun as a magnetic body. The components of the system producing the variations of the field from day to day, and also the disturbances, are entirely different in structure from those producing the hourly variations within the diurnal period, and they can not be derived from the same source. The latter are attributed to the effect of the electromagnetic radiation of the sun within the earth's atmosphere, as will be presently explained. This set of facts, both in general and particular, seems to me to be entirely inconsistent with the view that the solar magnetic field does not continuously modify the terrestrial field, and with the theory that a system of electric currents is generated by the solar radiation whose electro-magnetic effects produce the observed perturbations.

The two problems of the immediate future in terrestrial magnetism are as follows: (1) Is the magnetization of the earth, the other planetary bodies, and the sun due to their rotation in the ether, or to an internal process akin to ionization, or to molecular motions? All studies on the effect of rotation in the ether have heretofore shown that the resultant magnetic force is very feeble, if it exists at all. There is a probability that the atomic actions in the interior of these large bodies produce electric and magnetic forces which develop a planetary magnetism in conjunction with the prevailing high temperature. I am inclined to view the last proposition more favorably than the other. (2) Is the disturbance phenomenon of the earth's normal field due to effects transmitted in the electro-magnetic radiation or in a direct polar magnetic field? Some students are expecting to find in the action of the different kinds of waves transmitted in the sun's radiation an explanation of the diurnal and of the disturbance magnetic deflecting fields. These are, however, entirely different in their characteristics, and I believe that the view that they are both to be referred to one radiation must break down upon this fact.

TABLE 21.—*Rectangular components during the magnetic disturbance, February 12, 1892.*

	Horizontal deflecting force=0.000001 *dx*								Vertical deflecting force=0.000001 *dz*							
Time of impulse	San Antonio	Washington	Greenwich	Paris	Potsdam	Vienna	Pawlowsk	Melbourne	San Antonio	Washington	Greenwich	Paris	Potsdam	Vienna	Pawlowsk	Melbourne
12.00	−144	−144	−108	− 94	− 78	....	+ 42	+ 20	−40	....	+ 13	+ 47	+ 22	....	+ 106	−30
1.00	−144	−252	+ 20	− 59	+ 57	....	+387	+ 40	−50	....	+ 55	+ 84	+ 63	....	+ 324	−22
1.45	−211	−276	− 9	− 53	+ 26	− 18	+387	− 80	−60	....	+156	+153	+100	+56	+ 401	−26
2.08	−202	−324	− 44	− 73	− 52	−107	+387	−100	−60	....	+195	+169	....	+74	+ 372	−19
3.00	−225	−264	− 12	− 68	....	−135	+387	−100	−50	....	+221	+223	....	+93	+ 442	−19
3.20	−238	−252	+ 99	− 4	+ 10	−115	+387	+ 60	−50	....	+234	+251	....	+99	+ 442	+30
3.40	....	−300	+180	+ 97	+135	−111	+371	−160	....	....	+234	+260	....	+99	+ 413	+15
4.25	−270	−360	+ 93	− 50	− 31	−131	+238	−140	−40	....	+221	+325	....	+93	+ 372	+15
4.35	−283	−360	+ 75	+ 23	+ 42	− 74	+371	−160	−40	....	+221	+325	....	+93	+ 283	+19
5.20	−265	−360	+261	+125	+172	− 25	− 53	−140	−35	....	+221	+325	....	+93	+ 147	+22
6.00	−288	−360	+ 35	− 62	− 42	−107	0	−100	− 5	....	+234	+325	....	+87	+ 136	+37
6.25	−283	−180	....	+ 17	− 94	− 94	−148	−100	0	....	+234	+325	....	+81	+ 100	+41
6.53	−297	−192	....	+ 30	− 16	−135	− 42	−100	−20	....	+234	+223	....	+68	− 118	+52
7.10	−247	− 36	− 18	− 68	− 47	−139	−223	−110	+40	....	+234	+205	....	+56	− 242	+56
7.19	−301	− 48	....	− 15	− 47	−148	−334	−160	+10	....	+208	+214	....	+56	− 165	+67
7.38	−292	−108	....	− 39	....	−189	− 26	−120	+15	....	+195	+187	....	+62	− 118	+75
8.30	−301	− 48	−116	−144	−208	−266	−450	−260	+25	....	+182	+177	+100	+56	− 94	+82
9.25	−270	+216	−102	−129	−156	−217	−768	−310	+45	....	+156	+139	+ 70	+43	− 227	+97
9.55	−256	+ 24	−270	−289	−354	−328	−821	−330	+60	....	−122	+ 84	+ 50	+50	− 336	+97
10.26	−270	+ 96	....	−205	−218	−266	−297	−290	+55	....	+ 26	+121	+ 8	+31	− 283	+90
10.52	−256	− 72	−139	−121	−135	−185	−291	−280	+50	....	+ 57	+112	+ 45	+43	− 260	+75
11.26	−243	− 72	....	−114	−177	−201	−360	−290	+40	....	+ 55	+ 93	+ 20	+19	− 442	+52
11.45	−256	− 78	+ 69	−144	− 36	− 82	−970	−310	+20	....	− 26	− 19	− 80	+19	− 667	+22
12.26	−283	− 24	....	+152	−281	+ 41	−968	−200	+50	....	−156	−149	....	− 6	−1091	−30

+*dx* = increasing horizontal force northward in both hemispheres.
+*dz* = increasing vertical force downward in the northern hemisphere.
−*dz* = increasing vertical force upward in the southern hemisphere.

If *dx* and *dz* have opposite signs, the deflecting force lies athwart the normal magnetic field. The disturbances generally begin as vectors directed southward near the meridian, downward in the northern, and upward in the southern hemisphere. (W. B. Bul. No. 21, p. 78.)

TABLE 22.—*The horizontal and vertical deflecting forces, dx. dz, which generally have opposite signs. Example for March, 1887.*

March 1887	Horizontal deflecting force=0.000001 *dx*											Vertical deflecting force=0.000001 *dx*							Means	
	Los Angeles	Toronto	Greenwich	Paris	Pola	Prague	Vienna	Pawlowsk	Tiflis	Zi-ka-wki	Batavia	Greenwich	Paris	Prague	Vienna	Pawlowsk	Tiflis	Batavia	*dx*	*dz*
1	+32	+26	−23	+50	+22	+119	+31	+44	+3	−11	+20	+72	+70	−3	−69	+22	+68	−75	+28	+12
2	+68	+68	−1	+67	+59	+138	+38	+13	+22	−52	+38	+82	+45	−3	−79	+20	+27	−81	+42	+2
3	+102	+76	+41	+84	+96	+188	+90	+62	+110	+7	+79	−10	−30	−25	−95	−12	+26	−97	+85	−35
4	+102	+101	+37	+80	+83	+237	+85	+51	+118	+97	+126	+18	−5	−3	−92	−5	+25	−93	+102	−22
5	+7	+75	+2	+47	+60	....	−2	+10	+46	+66	+170	+63	+40	....	−101	+33	+24	−39	+44	+3
6	−74	−50	−110	−56	−63	....	−103	−81	−86	−135	−24	+78	+44	....	−12	+20	+52	+75	−78	+43
7	−16	−8	−91	−10	−36	....	−108	−32	−108	−145	−48	+96	+58	....	−21	+68	+60	+53	−60	+53
8	−90	−96	−88	−23	−9	....	−109	−73	−49	−86	+19	+62	+22	....	−38	+76	+9	−4	−60	+21
9	−42	−71	−143	−96	−82	....	−164	−144	−140	−217	−111	+98	+46	....	+2	−26	+98	−53	−121	+27
10	−45	−42	−20	+41	+5	....	−57	−45	−12	−147	−7	+7	+10	....	+11	+12	+37	−12	−33	+11
11	−32	−37	−55	−13	−28	−136	−87	−36	−23	−108	+33	+40	+14	−33	−4	+29	+16	−8	−47	+8
12	−26	+2	−55	−17	−31	−77	−63	−17	−25	−118	+15	+54	+8	−46	+22	+34	−15	−11	−37	+7
13	+23	−18	−72	+28	+36	−108	−15	+12	+24	−9	+20	+68	−78	−16	+37	+4	+43	−44	−8	+2
14	+71	+26	−62	+56	+127	−89	+13	+1	+42	−69	−29	+12	−54	+48	+5	+2	+19	−55	+8	−3
15	−15	−31	−49	−80	+40	−50	+37	+20	+50	−90	−18	−70	−50	+85	+18	+20	−10	−55	−17	−9
16	−29	−44	−144	−81	−88	−111	−94	−61	−31	−62	−68	−50	−92	−35	+35	−39	−5	+43	−74	−20
17	+44	−31	−49	+29	+4	−92	+23	−1	+8	−84	−88	−47	−104	+46	+8	+11	0	+79	−21	−1
18	+84	+51	−46	+28	+37	−32	+56	+19	+47	+134	+1	−105	−66	+62	−1	+11	−5	−19	+34	−18
19	+124	+76	−3	+78	+70	−3	+112	+88	+57	+172	+32	−98	−27	+27	+2	+21	−10	−37	+73	−17
20	+20	−10	−46	+47	+52	−13	+83	+38	+76	+250	+92	−124	−18	−29	−37	+2	−15	−92	+54	−45
21	−31	−51	−149	−64	−56	−124	−39	−22	−75	+48	−44	−90	+41	+67	−42	+12	−50	+23	−55	−5
22	−30	−47	−43	−44	−54	−75	−1	−23	−56	+126	−10	−188	+60	+21	+46	−8	−115	−35	−23	−31
23	−144	−109	+60	−5	−32	−5	−4	−13	+3	+94	+34	−194	+78	−25	+25	−27	−110	−33	−11	−41
24	−80	−69	+28	−86	−70	−46	−52	−53	−68	−28	−94	−177	+16	+61	+54	−67	−5	+30	−56	−12
25	+26	+9	+103	−26	−8	+64	+11	+36	−39	+90	−14	−117	+55	−8	+58	+13	−80	−16	+23	−13
26	−3	−5	+103	+3	+24	+53	+29	+16	+40	+98	+48	−93	+73	+38	+56	+24	−125	+53	+37	+3
27	+37	+34	+117	+2	−4	+42	+50	+6	+9	−45	+11	−41	+71	+3	+67	+24	−119	+69	+24	+11
28	−8	+19	+102	−18	−12	+2	+43	−5	−2	−77	−24	−3	+60	−9	+70	+24	−203	+86	+2	+5
29	+65	+31	+139	+61	+110	+1	+93	+5	+17	−30	+35	−30	+18	+14	+5	+4	−117	+81	+48	−4
30	+128	+37	+162	+80	+133	+40	+103	+65	+86	+58	+57	−28	−4	+31	−22	−35	−141	+69	+86	−19
31	+135	+82	+150	+130	....	+90	+100	+105	+125	+85	+100	+15	−5	+65	−49	−25	−135	+66	+110	−10

Sums of last columns taking the unlike signs is 1425; taking the like signs is 589.

In the time of disturbances the ordinary diurnal vectors are superseded and transposed into a different field at right angles to the ecliptic. If they did come from the same source, this could never happen, because the disturbance field would be an intensified diurnal field, which is not the case. Furthermore, the variability of the diurnal magnetic field ought to have a corresponding change in the intensity of the solar radiation, which has not been observed, for the atmospheric absorption can hardly mask the heat fluctuations if they have so pronounced counterpart variations in the magnetic field.

PHYSICAL PROCESSES IN THE EARTH'S ATMOSPHERE.

After having deduced certain results from an extensive computation on the magnetic deflecting forces in the earth's field, a brief account of which may be found in Bulletin No. 21, great difficulty was encountered in matching them with any known physical processes likely to take place in the atmosphere. In consequence of this defect the discussion halted till such advances had been made in experimental physics as would warrant taking up the incomplete exposition. At that time, 1897, but little progress had been made in explaining several facts which have since been accounted for by the theory of ionization, so that no advantage could then have been taken of a theory which had not passed beyond the stage of experimental hypothesis. But the case is now different, since the nature and action of the ions in a gas are well understood, and since it has been shown by **Elster** and **Geitel** that the theory of ionization is best fitted to cope with the perplexing contradictions which have been observed in the phenomenon of atmospheric electricity. This, in addition to the fact that ionization in the sun seems to constitute a very complete theory of the phenomenon of the solar corona in connection with a magnetic field, encourages us to expect that ionization in the earth's atmosphere, in conjunction with the solar and the terrestrial magnetic fields, constitutes the missing links which have so long baffled our research.

We may at this point confine our attention to two phenomena explained in Bulletin No. 21: (1) That the diurnal deflecting vectors seem to be generated as if the electro-magnetic or sunlight field had also the properties of a magnetic field; and (2) that the curve of intensity of the polar field at the earth is a wave line (p. 64) which differs considerably in form from that produced by plunging a permeable sphere or shell into an external magnetic field. Regarding the first phenomenon, it was stated that the required magnetic properties of the sunlight radiation was associated with atomic conditions (pp. 17, 34, 44, 79, 80, 81, 91, 164). On page 174 one reads:

> It is admitted that during the mutual readjustments of the magnetic field, currents of electricity exist throughout the atmosphere; also a change in the wave lengths of the electro-magnetic external field may be a source of the atmospheric electricity; but these subjects must be more fully studied, if possible, before a decisive statement can be offered. The synchronism between the solar and the terrestrial phenomenon, the periodicity and the inversion of types in the polar field, the peculiar distribution of the magnetic vectors in the electro-magnetic field, are therefore the chief points to be explained on the atmospheric electro-current theory. These currents, as well as the earth-electric current, are necessary consequences of the interaction of the three fields described, including their own variations in strength and the induced variations due to motion of the planet. But it is hardly possible to consider such electric currents as the true source of all the phenomena heretofore mentioned in detail.

Regarding the curve of intensity, a complete theory of the direction of the lines of force was given, namely, that the earth as a permeable shell is immersed in an external magnetic field generated by the sun, in which it was shown that the *direction* of the deflecting vectors at 26 stations agrees remarkably well with that of the theoretical lines of force deflected under such conditions. Regarding the intensity of the force nothing was said, because my ideas on the subject were at that time not sufficiently clear. Of course these incomplete statements laid my work open to adverse criticism by those who chose to be unfavorably impressed, but at the same time I believe it will be recognized that a very close approach was made to the heart of the problems involved, and that in fact there is but little to recall, because advance in recent physics points in exactly the same direction as that in which my own research was moving. It seemed to me especially important to discard two theories which are in vogue regarding the causes of terrestrial magnetic variations, namely: (1) The meteorological system of convectional air currents, because the facts of synchronism could not thus be established, and because the well-known mechanical convection has not the speed and direction necessary to produce the observed secondary magnetic field. (2) The atmospheric electric currents adopted by many magneticians were excluded, because the ether and the atmosphere are practically nonconductors, and prohibit widely extended currents of electricity from circulating around the earth. The conductivity which is due to various physical processes, such as ionization, is entirely too small to permit the induction of general magnetic fields by means of electric currents. The atmospheric conductivity is not large unless the air is highly rarefied, far below that of the atmosphere except on the outermost stratum, where the pressure is about 1 millimeter; and it is confined to the immediate neighborhood of the place of special processes, such as are produced by flames, electric discharges, cathode, RÖNTGEN, BECQUEREL, ultra violet and other radiations. Nearly all the authors who have worked along these lines, as SCHUSTER, SCHMIDT, and others, ascribe more conductivity to the atmosphere than seems to be justified by the facts. If the conductivity becomes metallic under restricted circumstances, then this must not be ascribed to the air generally, in order to produce the required magnetic fields, unless it can be proven that such special conditions exist. The conductivity accompanying ionization, which is simply due to the slow diffusion of minute charged particles, is of another order; the magnetic field attending it is of atomic origin *in situ,* and it is integrated by an application of the Ampèrean principle into a magnetic field, like an ordinary polar field with a potential.

PHYSICAL EXPERIMENTS ON RAREFIED GASES.

The facts derived from recent experiments are very numerous and important, but it is quite impracticable to attempt to reproduce many of them here. Numerous researches are conducted by means of vacuum tubes on account of the ease of their practicable manipulation; they are constructed with electrodes sealed in the ends for direct electric discharges, or they are electrodeless, provided with a coil outside, through which an oscillating electric current is passed. In these tubes one can study the relations of,

$p =$ the pressure of the gas in the tube in millimeters.
$d =$ the thickness of the HITTORF dark space in millimeters.
$i =$ the current in amperes.
$V =$ the tension in volts.
$E =$ the work done in watts.

The following example of these relations is taken from, "Unsichtbare Vorgänge bei elektrischen Gasentladungen," von H. EBERT, K. bayer. Akad. d. Wiss., 1898, Bd. XXVIII, Heft IV, page 503.

TABLE 23.—*Relations of the pressure, thickness of the Hittorf dark space, current, voltage, and work done in the vacuum tube under conditions of the greatest conductivity of air.*

p	2.76	1.30	0.83	0.51	0.27	0.20	m. m.
d	0.9	1.5	2.2	2.8	5.0	6.7	m. m.
i	12.61	15.76	15.94	15.39	13.49	12.37	m. amp.
V	718	574	559	602	725	812	volts.
$iV \times 10^3 = E$	9.05	9.06	8.98	9.27	9.77	10.06	watts.
Successive phenomena observed	Unstratified light		Light meets in the middle.	Stratification and striæ prevail			

It is seen that as the pressure continues to decrease the thickness of the HITTORF dark space increases, the current reaches a maximum and then diminishes; the voltage and the rate of doing work alike arrive at a minimum and then increase. The reversal of the electrical pressure indicates that a point is reached where the glowing unstratified light, extending out from the ends of the tube as rarefaction increases, meets in the middle and then, upon further decrease of pressure, breaks up into the striæ which are characteristic of the vacuum tubes. A mathematical analysis of this phenomenon is given by J. J. Thomson (Phil. Mag., March, 1899, XIX); this is extended by J. H. Jeans (Phil. Mag., March, 1900, XX) on the striated electrical discharge (compare Table 38). H. Ebert's experiments include tubes of different forms and dimensions, and with variable distances between the electrodes. There is found to be a relation between the "reversal pressure" and the wave length; the resistance and conductivity extend throughout the gas, but they differ in different parts of it; the action leading to increased conductivity occurs first along certain paths, and then passes over into others as the conditions vary; the action of a magnetic field is to quench the light; electro-motive forces of resistance are developed. The order of the process is somewhat as follows:

(1) Discharges of electricity.
(2) Ionization of the gas in rarefied spaces.
(3) Increase in conductivity.
(4) Increase in electrostatic potential.
(5) Reversal pressure effect.
(6) Shifting the path of transmission effect.
(7) Diffusion of the ions with different velocities.
(8) Effect of the magnetic field to quench, deflect, or change the light.

The phenomena of the deflection of a cathode stream by a magnetic field in its neighborhood, the helical rolling of the paths of the cathode rays by a superposed magnetic field, which show that the magnetic lines of force are vortices in the ether about their axes, and that the motion of the ether is rotational within them, are so well known that we may pass to a fuller statement regarding the action of the electrostatic force upon small masses charged with electricity, such as compose the cathode rays, or the ions into which air and aqueous vapor may be decomposed under certain conditions. A paper by H. Ebert, "Das Verhalten der Kathodenstrahlen in Electrischen Wechselfeldern," Ann. der Physik und Chemie, 1898, Band 64, contains the description of experiments applicable to this subject. A Braun'sche vacuum tube, provided with a diaphragm and screen for observing the position of the bundle of cathode rays, is placed between two small plates which form the ends of an open circuit. The wires lead to a transformer such that a current, with maximum voltage 2149 and period number 520, discharges across the tube at the point of the diaphragm. The electrostatic force is observed to vary in a smooth sine curve, and it is found that the ends of the cathode rays also execute precisely the same curve; this is shown by means of a rotating mirror formed of phosphorescent material which serves to retain and draw out the image. The evidence is positive that the position of the charged particles in the cathode rays pulsates synchronously with the vibrations of the electrostatic field. The question is discussed whether it is the magnetic force which is generated by the varying electrostatic field according to the law of curling,

$$\text{curl } \mathbf{H} = \omega c \frac{d\mathbf{E}}{dt}, \quad \text{where}$$

ω=the area of the electrostatic field (the plates).

c=the dielectric constant of air$=\frac{1}{9\times 10^{20}}$.

$\mathbf{E}$=the electrostatic force.

$\mathbf{H}$=the line integral of the magnetic force in a circuit around the edge of the plates.

The deflection produced by bringing a small magnet near the cathode bundle was 3 centimeters for a force of 0.1200 C. G. S. The same deflection is produced under circumstances such that the value of $\mathbf{H}$, computed by the formula, curl $\mathbf{H}=\omega \,.\, c \frac{d\mathbf{E}}{dt}$, is only $\frac{1}{300000}$ part of that quantity.

Hence, the conclusion follows that it is not the induced magnetic forces in a pulsating electrostatic field which produces the observed deflection. This is, however, accounted for as follows: When cathode rays are generated in rarefied gases in a tube by electric discharges across the space of low pressure, the sides of the containing tube are heavily charged with static electricity, negative near the cathode and positive near the anode, on the inside of it. The uniform distribution of these charges on the walls of the tube hold the cathode rays in the center by an equally distributed electric pressure on all sides. Now, if this distribution is disturbed by the approach of an electric or a magnetic body to one side of the tube, the cathode rays bend to conform with the new position of equilibrium. The action of the small condenser plates on the outside of the tube was to periodically disturb the electric pressure as represented by a sine curve, so that the end of the cathode bundle moved synchronously with it. This shows that changes in an electrostatic field are followed by corresponding variations of position of the charged particles of the cathode bundle. EBERT also balanced a magnetic force against an electrostatic force, the two fields, being at right angles to one another, and the result was that when the fields were pulsating synchronously the end of the cathode bundle executed well-defined LISSAJOUS figures, which means that the charged particles are equally subject to deflexion by magnetic and electrostatic forces.

Now the charged particles or ions in the atmosphere likewise respond to the variations in the electrostatic and the magnetic fields which traverse it, and these two fields must react upon each other through the medium of the ions. If the ultra violet radiation, from the sun or any other source, generates ions at one point in the atmosphere more abundantly than at others, and if at some points the ions recombine and eliminate their electrostatic effects by forming neutral masses, then it follows that both the electrostatic fields and the magnetic fields must be deflected, and take up new positions in harmony with these changes. *This is evidently a sufficient cause for the diurnal variations of the magnetic field, and of the atmospheric electric potential fall or gradient.* There is thus no need to invoke electric conduction currents to account for the phenomena of the diurnal magnetic deflections. Indeed the nonconductivity of the air is not sufficiently overcome by ionization to permit such currents to induce enough magnetic force, especially so as under the very favorable conditions of the EBERT transformer, with 520 pulsations per second, the magnetic force is much too small. If in the air we require a deflecting force of about 0.00012, then with a pulsation of 150,000 per second there would be something like the right order at the same voltage. At higher voltage, as 15,000 per centimeter, the periodicy could be decreased. This order of electric and magnetic quantities can not be wholly improbable in the air, so that there may really be some magnetic effect due to rapid minute variations in the atmospheric electricity. EBERT also observed true phosphorescent light at the glass just beneath the electrostatic plates when undergoing vibrations. These experiments make it quite clear what kind of processes in the atmosphere give rise to the phenomena of the terrestrial magnetic and electric fields without resorting to other less probable theories. In order to bring the facts of atmospheric electricity together for comment, a brief recapitulation of certain results will be given.

THE PHENOMENA OF ATMOSPHERIC ELECTRICITY.

ELSTER and GEITEL have recently applied the theory of ionization in the atmosphere to account for the phenomena of atmospheric electricity with considerable success, so much so in fact that it is by far the most promising theory on the subject. M. A. B. CHAUVEAU estimates that there are about thirty well-defined theories of the origin of atmospheric electricity, some vague and improbable, others accounting at least in part for certain features in the complex conditions. That electricity should be generated in many ways at the earth's surface and in the air itself is probable, but the important object for science is to acquire a working hypothesis of the cause and action of the great part of it. The older theories of EXNER, that electrification is chiefly associated with the evaporation, condensation, and convection of aqueous vapor, and of ELSTER and GEITEL, that the escape of negative electricity is accelerated by the action of ultra violet light on metallic and other surfaces, have been perhaps most considered of late years.

The latter has, however, been modified in favor of the ionization theory, which we shall briefly recapitulate.

The electrostatic lines of force in the atmosphere are practically vertical, and the higher strata are positively charged, while the surface of the earth is negatively charged in normal conditions. The electric gradient is approximately 130 volts per meter, but it decreases upward and, according to balloon observations, *disappears at an altitude of about 5,000 meters*, where the lower cloud system may be assumed to terminate. If the surface of the earth is level the vertical lines are nearly parallel; if it is mountainous the lines of electrostatic force concentrate on the peaks and forsake the valleys, so that the equipotential lines become curved and are perpendicular to the gradient lines, the peaks being more highly charged than the valleys. If a positive charge of electricity moves downward and a negative charge moves upward, there is an electric current from the air to the earth which is called *negative;* if a positive charge moves upward and a negative downward a *positive* current passes from the *earth to the air.* Displacement currents are caused by local temporary disturbances and readjustments of electricity.

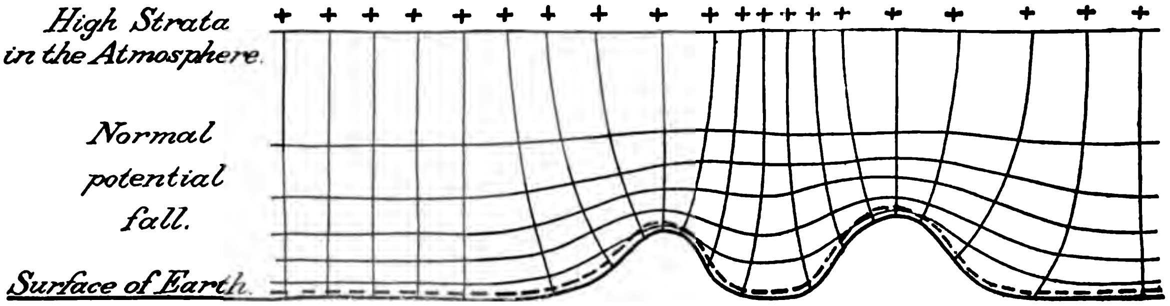


CHART 27.—Scheme of the distribution of the electrostatic lines of force in the atmosphere.

If c=the permittivity or dielectric constant$=\frac{1}{9\times 10^{20}}$,

E=the electrostatic force,

D=the displacement, we have, $\frac{c\mathbf{E}}{4\pi}=\mathbf{D}$.

Then $\omega \,.\, c\,\frac{d\mathbf{E}}{dt}=\omega c\dot{\mathbf{D}}=\text{curl }\mathbf{H}$=the line integral of the magnetic induction **B** which is equal to the magnetic force **H** in the atmosphere around the bounding curve of the surface ω.

The electric lines of force are associated in tubes; an electric displacement along the axis of each tube generates a magnetic force around the tube such that, $4\pi\times$ current through the closed curve=the line integral of the magnetic force round the curve=curl **H**.

$$\omega c\dot{\mathbf{D}}=\omega \,.\, c \,.\, \frac{d\mathbf{E}}{dt}=\text{curl}_\omega\ \mu\mathbf{H}=\text{curl}_\omega\ \mathbf{B}.$$

In the electrostatic system of units the magnetic inductivity for air is $\mu=1$, and since $\mu cv^2=1$, where $v=3\times 10^{10}$, the velocity of light or the ratio of the electrostatic units to the electromagnetic units $c=\frac{1}{(3\times 10^{10})^2}$. The line integral around a bundle of single tubes is by the Amperean principle and by STOKES theorem equal to the line integral around the bounding surface. As already stated, the magnetic force is usually very minute in the displacement of electricity in the atmosphere, though it may be considerable in the case of a lightning discharge. The electrification at any point is ρ=divergence **D**, that is the degree of concentration of the electrostatic lines within an area as referred to the normal number belonging to the area.

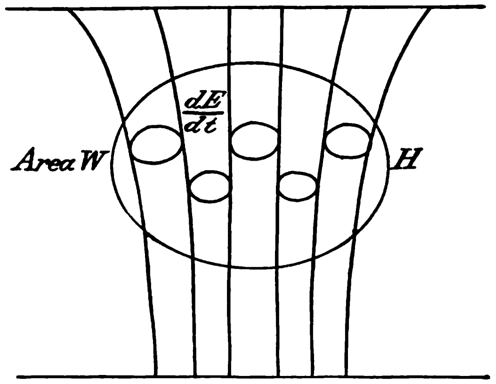


CHART 28.—Variable electrostatic force in a given area and the resulting magnetic force.

This is illustrated over mountain tops where there is convergence, and in the valleys where there is divergence. If the medium containing electrification is moving through the ether with the velocity $\mathbf{u}$ there is a motional current $\rho\mathbf{u}+\mathbf{j}$. This is the case in the atmosphere, since there is a steady drift eastward in the higher latitudes and a westward drift in the lower or tropical latitudes. The amount of magnetic force developed by this mechanical circulation is not large, but it has been utilized by **Trabert** (Met. Zeits., Nov., 1896, p. 410) to account for certain phenomena in atmospheric electricity which, however, are more probably due to ionization. There is still another source of current in the atmosphere depending upon the conductivity of the air, k, where $\mathbf{C}=k\mathbf{E}$. This quantity k is the one which is vanishingly small in pure nonconductors, as the ether and normal dry air, but which has been practically assumed by some authors to be large enough to permit the atmosphere to be traversed by long and persistent electric currents capable of inducing true magnetic fields. Thus the permanent magnetism of the earth has been referred to that source; certain local deflections of the normal magnetic field have been assumed to depend upon local electric circuits equivalent to a ring circulation (Ad. Schmidt, Meteorol. Zeit., Sept., 1899, p. 385, and Terr. Mag., March, 1890, p. 9) with the well-known distribution of magnetic induction $\mathbf{B}$. These electric currents are said to be located in the lower strata of the atmosphere, and they may not be referred as such to the thin high stratum where the conductivity is greatly increased in consequence of the extreme rarefication of the gaseous medium. We shall enlarge upon the conductivity factor in the next section. It is finally to be concluded that the total electric current is

$$\mathbf{J}_\circ=\mathbf{C}+\dot{\mathbf{D}}+\rho\mathbf{u}+\mathbf{j}=k\mathbf{E}+\frac{c}{4\pi}\,\frac{d\mathbf{E}}{dt}+\rho\mathbf{u}+\text{curl}\,V\,.\,\mathbf{Dq}=\frac{\text{curl}\,(\mathbf{H}-\mathbf{h}_\circ)}{4\pi},\ \text{per unit area.}$$

THE DIFFERENT SOURCES OF MAGNETIC FORCE IN THE EARTH'S ATMOSPHERE.

The first term $k\mathbf{E}$ is the current depending on conductivity, and if the atmosphere possessed something like metallic conductivity, it would be the seat of continuous electric currents through the air, which would induce true magnetism, just as the electric earth currents do in the body of the solid earth. It can be shown clearly that within the region open to the exploration of atmospheric electricity there exists no conductivity comparable with that in the earth, and such experimental measures have already been carried to great heights in balloon ascensions, 16,000 meters. The second term gives the displacement currents per square centimeter, and these are the oscillations which occur along the electrostatic lines, as from the cloud to the earth in lightning discharges. It is probable that there exists a pulsation at such times more or less pronounced along the electric lines in a vertical direction, and a magnetic force due to such vibrations would be developed whether they are periodic or not. The fact that photographs of lightning discharges show that the air is cracked or fissured like brittle glass, and that the electricity apparently forces its way only after a breakdown of the dielectric takes place, indicates that normally the air is a powerful nonconductor, but that during the lightning discharge ionization takes place rapidly, and the zigzag paths of light probably show where the air is most susceptible to dissociation and to an increase of conductivity. The third term indicates that an electric current may be formed by the rapid transference of the electric density from one point to another. Thus the passage of electric currents in the earth may disturb the surface density, or the physical processes in cloud formation may cause a change in the place where the positive charges congregate together. Such changes in electric density in the upper and lower strata cause a shift to take place laterally in the electrostatic lines. These are no doubt perpetually swaying to and fro in the atmosphere. In consequence of the motions of the electrostatic lines from side to side there is generated the current $\rho\mathbf{u}$ at a given place, and this, too, is the source of a magnetic field, Finally, the fourth term $\mathbf{j}=\text{curl}\,V\,.\,\mathbf{Dq}$ means that if the medium itself is in motion so that the electric displacement $\mathbf{D}$ is moving with the velocity $\mathbf{q}$ there is formed a magnetic force at right angles to the plane $\mathbf{Dq}$. Thus in the atmosphere we have electrostatic lines stretching vertically up and down, and they are moving eastward with a velocity $\mathbf{q}$ in the higher latitudes, or westward in the lower latitudes, so that there is generated magnetic force pointing *northward in the higher latitudes, but southward in the lower latitudes.* The vector product rule is that $V.\,\mathbf{Dq}$ signifies that if $\mathbf{D}$ is positive upward and $\mathbf{q}$ is motion eastward, then by right-hand rotation of $\mathbf{D}$ to $\mathbf{q}$ the magnetic force is northward; or if $\mathbf{D}$ is positive upward and the motion westward, as in the Tropics, then there is magnetic force southward. The rotation curl $V.\,\mathbf{Dq}$ means that the generation of the magnetic force $V.\,\mathbf{Dq}$ is accompanied by the electric current around it as an axis, in accordance with the line integral or curl principle. Furthermore, it should be noted that since the strata of the atmosphere move faster above than below in the higher latitudes, there must be a distinct variation in the displacement $\mathbf{D}$, which is another way of giving rise to the second term type of currents, and it should be added to those already described as oscillations along the electrostatic lines of force. Likewise, the motions of the atmosphere in cyclonic and anticyclonic circulations give rise to other variations in the displacement, so that a very complex system of conditions really binds together the electric and the magnetic fields in the atmosphere. Since action is equal to reaction, it follows that when the polar magnetic field from the sun impinges on the earth's atmosphere, any oscillations in it caused by solar pulsations must be resolved through a similar train of physical processes, first to the ions of the atmosphere, and thence to the gaseous masses which enter into the ordinary meteorological circulation. Thus a true physical connection is established between solar and terrestrial magnetic forces, and between these and the circulation of the atmosphere in storm circulation. From this point onward one can do little more than repeat the statements which have already been published in Bulletin 21 of the Weather Bureau. We will therefore emphasize some of the points which more closely concern the process of ionization in the atmosphere.

Referring now to Chart 27, which shows the courses of the normal electrostatic lines between the air and the earth, the theory of ionization supposes that in undisturbed normal air an equal number of positive and negative ions exist, but that in the case of a conductor surrounded by ionized air the negative ions always seek the conductor; hence, in the case of the earth it must be negatively charged with electricity while the atmosphere is positively charged. The weak point in the theory is to show how and why the atmosphere becomes thus heavily ionized, how the molecules or atoms of air and aqueous vapor become dissociated on a large scale, even admitting that conditions exist for producing ions to a limited extent. One naturally assumes that it is the ultra violet radiation of the sun which causes the dissociation, but Elster and Geitel remark (Terr. Mag., Dec., 1899, p. 230):

> Where the source of this condition is to be sought remains as yet unanswered, though it is probable, since the conductivity increases with the height, that it lies in the higher strata of the atmosphere. As yet there exists no ground for referring it back to an action of the sunlight.

However, since the ions really exist in the atmosphere, their history may be followed with some degree of accuracy. If by dissociation the ions are produced in the upper strata, then by gravitation acting upon them and by diffusion they seek the surface of the earth, which is a conductor. The property of the negative ions to travel faster than the positive ions is due to the much smaller masses of the carriers of the negative charges. The negative ions arrive at the surface in greater numbers than the positive, and thus by accumulating a charge which repels other negative ions there is built up a balance between the gravity, which draws the ions down, and the electricity, which repels them upward, so that an electrostatic equilibrium tends to become established. Therefore the work which is represented by the tension along the lines of force in an electrostatic field is to be referred to the action of gravitation. The charges travel by the way of the lines of force, and seek the mountain peaks, the valleys, or the plains, as the case may be. These are the conditons which belong to clear weather.

In obscure weather, when mist, fog, smoke, and condensation products prevail in the atmosphere, as in certain zones of the earth more than in others, as in cyclonic areas relative to anticyclonic, in the afternoon relative to the forenoon, the foregoing state of affairs is somewhat modified. The negative ions have been shown to serve, just like dust particles, as the nuclei of condensation for aqueous vapor, so that rain drops are readily built up around them. But an ion loaded with vapor loses its capacity to travel rapidly toward the ground, and becomes tangled in the body of the cloud, so that the negative charges tend to accumulate on the bottom while the positive charges congregate on the tops of the clouds. This separation of positive and negative electricity on the upper and the lower surface of clouds always exists, and it may grow to many thousand volts per meter, so that finally the insulating strength of the air is broken down and a lightning discharge takes place. Evaporation of aqueous vapor carrying upward negative ions from the earth by the ascensional force of the air may increase the negative electricity on the lower surface of clouds. When drops of rain fall some negative electricity returns to the ground, but it is not a very large quantity. The action of the wind disturbs the travel of the ions along the lines of electrostatic force toward their opposite charges. The many complex conditions at the earth, the distribution of vegetation, surface masses, charges on the ground, on buildings, near waterfalls, the variations due to the smoke of cities, mechanical electric currents, and a thousand other circumstances make the observations on atmospheric electricity difficult, and the results more uncertain and unsteady than in any other meteorological element. The local circumstances so far tend to disturb the average general distribution of electricity that it is not an element suited to observations with the purpose of providing a reliable basis for forecasting. As is well known this element is much less valuable than the magnetic field surrounding the earth for that object, because the latter transmits pulsations which embrace synchronously the entire earth, and it also has a distinct connection with the solar activity, which is the primary source of the energy.

THE CONDUCTIVITY OF THE ATMOSPHERE AS MEASURED BY EXPERIMENTS.

A series of careful experiments were first made by Linns (Meteorol. Zeit., 1887, p. 352) to determine the rate of dissipation of charges of electricity in free air, the charge being maintained at a constant potential. The result was that about one hundred minutes were required for a charge to dissipate itself. This is interpreted to mean that pure dry air has a very slight degree of electrical conductivity. These experiments have been repeated by Elster and Geitel (Terr. Mag., Dec., 1899) with improved apparatus, and in various localities, in order to find the influence of the place upon the rate of dissipation. Table 24 collects these results, and gives in the first column the locality and the kind of place, as mountain peak or valley, lowland, near falling water; the second and third columns contain the percentage of loss per minute for positive and negative charges, respectively; the fourth and fifth columns, the corresponding minutes required to dissipate a charge.

Table 24.—*Rate of dissipation of positive and negative charges of electricity maintained at a constant potential.*

ELSTER AND GEITEL.—CLEAR WEATHER DISSIPATION.

Stations	Percentage of loss per minute		Time for the loss of the total charge	
	Positive	Negative	Positive	Negative
Lowlands	0.4	2.6	250	39
Brocken Peak, 1140 m.	1.4	2.6	71	39
Santis Peak, 2500 m.	6.2	6.7	16	15
	2.0	6.9	50	14
	1.9	8.3	52	12
Termatt Valley, 1620 m.	4.5	4.4	22	22
Riffelhauses Plain, 2600 m.	4.4	6.8	22	15
Gornergratbahn Pass, 3000 m.	2.7	7.0	37	14
Gornergrats Peak, 3140 m.	0.7	6.6	143	15
Termatt base of waterfall	16.2	1.9	6	52
Small room	0.7	0.7	143	143

It is seen that negative electricity dissipates faster than positive, especially on mountain peaks, where it may assume almost a unipolar type. In mountain valleys the rate is more nearly equal for each electricity, also in small rooms, but near the base of a waterfall the positive dissipates so much faster than negative as to become unipolar of the opposite type to mountain peaks. Hence it is concluded that mountain peaks are rich in positive ions, and the localities at the foot of waterfalls are equally abundant in negative electricity. The dissipation is explained by the fact that the ions in the upper air seek the earth along the lines of electric force, the positive accumulating on the mountains and the negative in the valleys, by these physical processes. It was found that the force of the wind has little to do with the rate of dissipation; that the presence of clouds, mist, and other causes of obscuration of the sky greatly retards dissipation, because the ions become entangled in the cloud and are not free to move to the ends of electrostatic lines, where the charges can be neutralized. The rate of dissipation is smaller in winter than in summer; smaller in the morning than at night. Cloud building in negatively ionized air takes place at lower pressure and warmer temperature than in positively ionized air, so that cyclones are associated with negative ions and anticyclones with positive ions. The cloud itself is a mixture of dry air containing positive ions and water drops containing negative ions, and therefore falling drops leave positive ions remaining in the air. The diurnal and yearly periods of atmospheric electricity are very closely connected with these processes. Positive potential fall is the rule and a negative gradient the exception, this latter being difficult to account for at all on the ionization theory.

H. **Ebert**, at Munich, Germany, on June 30, November 10, 1900, and January 17, 1901, made balloon ascensions to about 3,000 or 4,000 meters, and carried the **Elster-Geitel** form of apparatus for measuring the rate of dissipation of electricity from a charged body. He found that this was an entirely practical procedure and obtained important and interesting results bearing on the ionization and conductivity of the air.

Examples.

November 10, 1900			January 17, 1901			
Height	Rate of dissipation		Height	Rate of dissipation		
Meters			*Meters*			
1975	$a_+=1.16\%$	$q=1.81$	995	$a_+=0.41\%$	$q=4.58$	
2160	$a_-=2.10$		1275	$a_-=1.89$		
2275	$a_-=2.29$	$q=1.28$	1470	$a_+=4.01$	$q=2.18$	Cage was used
2420	$a_+=1.79$		1550	$a_-=9.53$		
2890	$a_+=1.17$	$q=1.40$	1930	$a_+=1.03$	$q=2.07$	
2965	$a_-=1.63$		2285	$a_-=2.13$		
3400	$a_+=2.50$	$q=1.10$	2375	$a_+=13.86$	$q=1.08$	Cage was used
3705	$a_-=2.75$		2560	$a_+=11.04$		
3710	$a_-=2.76$	$q=0.93$	2880	$a_-=12.16$		
3770	$a_+=2.96$		2930	$a_-=17.48$		
			3005	$a_-=14.03$		
			3105	$a_+=1.02$	$q=5.10$	
			3060	$a_-=5.20$		

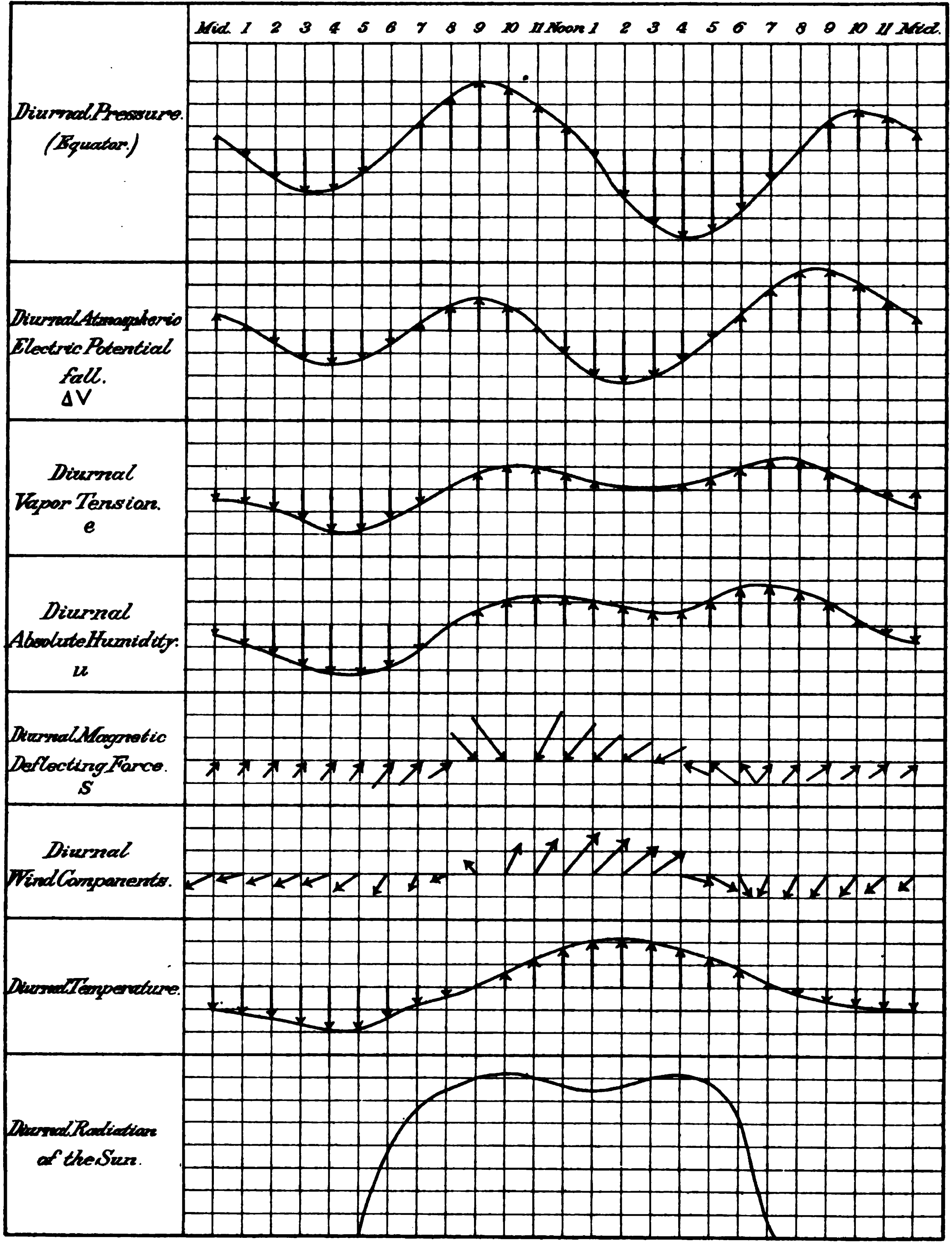
a_+=the percentage of loss of the original positive charge maintained at a constant potential per minute; a_-=the same for the negative charge. $q=\frac{a_-}{a_+}$, the ratio of the negative to the positive rate. An inspection of the examples of November 10, 1900, and January 17, 1901, shows that generally there is a unipolar type at the ground, where the negative sign preponderates, and that the positive and negative rates become about equal in the neighborhood of 3,000 meters. The values of a_+ and a_- tend to become larger with the altitude, though the irregularity in the data does not permit a sure deduction from these few measurements. Interpreted in the language of ions, the negative ions are in excess at the ground, but become equal to the positive at about 3,000 meters, so that this is probably the region of special activity of ionization in the atmosphere. The conductivity of the air increases upward; the number and the activity of movement of the ions shows that it becomes greater in the strata of less pressure. The increase of the values of a_+ and a_-, wherever the ion catch-cage was used, is shown by the large values obtained in the ascension of January 17, 1901. This method permits more rapid readings, a new one every five minutes, and thus quick measures of the electric condition of thin strata. The electric and the meteorological conditions change suddenly at different levels whenever there is passage from one overlying stratum to another. The atmosphere is very strongly stratified by currents of different constitution and the electricity follows this discontinuity, so that general laws do not usually prevail in a particular ascension without very marked exceptions. All this is in conformity with the ionization theory of the origin of atmospheric electricity, and it justifies the continuance of such observations by means of balloons.

According to the above experiments, a positive charge in free clear air dissipates in about seventy-five minutes, and a negative in about twenty-five minutes, and the rate of negative dissipation is three times as fast as that of the positive. If the earth gives up its negative charge to the air at this rate it would mean that an exceedingly vigorous source of supply must be continuously in action to recharge it. However, the important conclusion for our main purpose is the establishment of the fact that the *coefficient of conductivity in free air is so very small that the magnetic induction to be derived from true conduction currents is insignificant.* Also, that the theories of terrestrial magnetism depending on electric currents in the atmosphere must be excluded except for a shallow stratum of very highly rarefied air near the upper boundary of it. Further evidence of its efficiency in generating electric currents than we now possess must be obtained before it can be admitted to account for the comparatively large magnetic forces which are measured at the earth's surface.

THE DISTRIBUTION AND THE DIURNAL VARIATION OF ENERGY IN THE EARTH'S ATMOSPHERE.

We will now proceed to a more specific summary of the facts regarding the distribution and the variation of energy in the atmosphere, as expressed in the diurnal changes of pressure, vapor tension, and absolute humidity, electric potential fall, temperature, magnetic deflecting forces, and diurnal wind components. The diurnal periods of all these elements except perhaps the temperature have been a source of perplexity to meteorologists, so that all possible information regarding their connection with solar radiation is important and valuable. The curves or the vectors denoting the variations on the daily mean at the several hours of the day are compiled from readily accessible data, and as less stress is to be laid upon the magnitude of the deflection than upon the laws of the mean distribution, the discussion will be carried on in general terms. A quantitative analysis of these interdependent elements is in progress, but the result is not yet available. The curves on Chart 29 of the diurnal pressure at the equator, and the wind components are taken from the International Cloud Report, pages 466, 476; that of the diurnal atmospheric electric potential fall or gradient is compiled from observations made at 17 different stations, including MENDENHALL's series in the United States, Greenwich, Perpignon, Batavia, Paris, etc.; that of the diurnal magnetic deflecting forces, from Bulletin 21, Table 19, for middle latitudes; the temperature from Weather Bureau data; those of the diurnal vapor pressure and absolute humidity from the report on the barometry of the United States, Volume II, Annual Report Chief Weather Bureau, 1900–1901, and comprise the mean result from 234 stations. The diurnal radiation of the sun in calories per square centimeter per minute is taken from HANN's Meteorologie, page 38. An inspection of these curves shows conclusively that the *diurnal pressure, vapor tension, and electric potential variation are of the same type*, and hence it is proper

CHART 29. Diurnal variations of the meteorological, electrical, and magnetic elements in the atmosphere of the earth.



to infer that they all must be referred to the same cause. The magnetic force *s* and the wind components are evidently vector systems, not only related together, but practically identical, except that the direction of the magnetic vectors are the reverse of the wind components. The temperature curve has the same trend as the first group during the night, but it is not reversed from about 10 a. m. to 7 p. m. during the day. This is readily seen by comparing the temperature and the vapor tension curves. If the vapor tension curve were to complete its crest, then the temperature type with one maximum and minimum would be reproduced. It is believed that the true type curve is that of the temperature, but it seems to be disturbed in the other elements by superposing upon it a reversal during the midday and afternoon, as if the physical process which progresses in the forenoon hours of the day were arrested and reversed during the warmest part of the day. The radiation curve shows a similar midday reversal of activity, and at the surface of the earth there is less heat received than during the hottest portion of the day. It is known that the double diurnal period in the pressure, electrical potential and vapor tension becomes a single period at a distance of 1,000 to 3,000 meters above the ground, so that the inversion is confined to the lower strata. Dr. HANN discusses this phenomenon only a little, but associates the variation with the diathermacy and absorption of the atmosphere. The physical questions involved are very difficult to settle because of the lack of suitable observations throughout the gaseous envelope of the earth. These several terms no doubt indicate the effect of the absorption of the solar energy in the air. It is especially to be remarked that these diurnal changes all begin promptly with the commencement of the morning radiation; they rise to a maximum before noon in all cases except that of the temperature, which continues to increase till about 2 p. m. It seems as if the pressure, and the electric potential, start in a wave about 10 a. m., and that the secondary evening wave may be in some way reflected from it by simple reaction. The morning wave is so distinctly connected with the rise in radiation that it must be regarded as the real thing to first explain, expecting that the evening wave will find its cause in a rebound from the other. We shall venture some further remarks on this obscure subject. Thus, if the dissociation of atoms by ionization, as indicated in the electric potential curve, proceeds most rapidly at 9 a. m. and 9 p. m., it has in some way been hindered so that even a recombination goes on during the afternoon and later at night. In the same way, if the pressure increases till 9 a. m. to a maximum it is arrested and a minimum occurs in the afternoon, but it is resumed in the evening. The same may be said of the vapor tension. I shall suggest that the formation of ions and their redistribution by the more rapid movement of the negative charges to earth leaves a maximum of positive ions in the air at 9 a. m. and 9 p. m. Since these are of the same sign and associated with the particles of air, there must be electric repulsion between them, and no doubt other physical forces, acting to produce a similar effect. But with the increase of heat at midday and the ascensional movement from the ground of negatively charged masses, dust and other small particles, rather than ions, by the buoyancy of the air derived from the surface heating, there is caused the well-known diurnal convection, through which the negative charges are returned to the upper layers; then recombination of the ions occurs, and the repulsive forces are neutralized, so that there is a fall in the dry air and vapor pressures. An attempt will be made to establish this proposition quantitatively in the future, being content now with pointing out that the movement is in the right direction at all parts of the day, though the evening wave is more difficult to understand. This is in harmony with my discussion in Chapter 9 of the International Cloud Report, which does not accept the validity of the thermic theory nor the forced oscillation theory, but does refer the action to a static attraction or repulsion there summarized as magnetic attraction. It may be noted that nearly all my work has resulted in an apparently necessary endeavor to refer these remarkable phenomena back to a system of forces acting statically *in situ*, rather than to dynamic currents, either of the circulation of the air or electricity.

Finally, it is shown on the 30-inch globe of deflecting magnetic vectors described in Bulletin No. 21 that there are in the middle latitudes two turning points in their direction, such that they point generally eastward from 7 p. m. to 10 a. m. and westward from 11 a. m. to 6 p. m. An attempt is made on Chart 29 to indicate the vertical directions by printing downward vectors in red ink and upward vectors in black ink. These two turning points are distributed symmetrically to the maxima of the vapor tension curve, and hence to all the other curves of the system more or less exactly. The strength of the deflecting magnetic vectors varies greatly in different latitudes, as shown on Chart 30, so that one should not draw too rigid conclusions from the length of the vectors, but should also consider the positions of their turning points. The first row of vectors pertains to the north polar belt which terminates at latitude 60°; the second to the north temperate belt which terminates at latitude 30°; the third to the tropical belt which extends from 30° north to 30° south; the fourth to the south temperate which ends in latitude 60° south; the fifth to the south polar belt, which is of course conjectural. Dr. H. **Fritsche** has recently discussed the diurnal deflecting vectors from the point of view of the **Gaussian** Potential Theory, finds a similar distribution, and concludes that they can not be caused by a potential inside or outside the earth, but that electric currents might do the work if they can be accounted for by suitable physical processes.* These belts are bounded in latitude by the disappearance of the vertical component, and this is accompanied by a sudden change in the direction. Generally speaking, there is a marked system of disturbances in longitude at the 9 a. m. and the 9 p. m. hours, which corresponds very closely with the maxima of the diurnal pressure, the atmospheric electricity, and the vapor curves. This remarkable parallelism between the several elements, therefore, suggests that the explanation is to be found in those changes produced *in situ* in the atmosphere by the action of solar radiation upon its constituents, of which ionization is one important manifestation. This transformation of energy, as expressed in the common meteorological elements, in atmospheric electricity and magnetism, renders the entire subject of the physical conditions and the partially understood laws which govern them of especial importance and interest to meteorologists. One can not fail to note that the diurnal magnetic system is marked off approximately by the same parallels of latitude, namely: 30° and 70°, which divide up the atmospheric circulation into the well-known belts, tropical, temperate, and polar.

THE VARIATION OF THE METEOROLOGICAL, MAGNETIC, AND ELECTRICAL FORCES IN LATITUDE.

There is yet another branch of the subject of the relation of the magnetic vectors and the electric potential to the meteorological elements, which will be introduced by referring to several other papers on these topics, namely, those concerned with the variation in latitude of the vectors expressing the changes in longer intervals of time than the diurnal period. In the Amer. Journ. Sci., August, 1895, I published a paper on The Earth a Magnetic Shell, showing the results of a computation on the vectors which are superposed upon the normal magnetic field at 26 stations, varying in magnetic latitude from Kingua Fjord +78° to Hobarton −55°. This was explained fully in Bulletin No. 21, and Table 25, Section I, is reproduced from it. Under the mean values are given the elements of the vectors, collected according as the direction is southward or northward, respectively. If the diurnal values for H. D. V. are plotted on a base line, so that the curve covers many days, the variations $-\Delta H$ from the mean indicate that the curve of the horizontal force is deflected below the line, and $+\Delta H$ above it; $-\Delta D$ to the eastward and $+\Delta D$ to the westward of the magnetic meridian; $-\Delta V$ upward in the northern hemisphere and $+\Delta V$ downward. Combine these rectangular coordinates into equivalent polar coordinates, so that $s=$ the total deflecting vector, $\sigma=$ its horizontal trace, $\alpha=$ the angle that s makes with σ, and $\beta=$ the angle that σ makes with the magnetic meridian, where $\beta=0°$ is northward, $\beta=180°$ is southward. The several stations were computed for all variations throughout a single year, and the resulting angle β is so close to the magnetic meridian as to satisfy the theoretical condition that an external field produces no east-west component. The vectors were slightly adjusted as to length by graphical construction, as indicated; the angle α was computed from $(\sigma \,.\, s)$ because the mean of the α angles is much less correct, as explained in the text of W. B. Bulletin No. 21.

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*Die Tägliche Periode der Erdmagnetischen Elementen, von Dr. H. Fritsche, St. Petersburg, 1902.

Typical vectors of the magnetic deflecting force in the principal diurnal belts.

CHART 30.

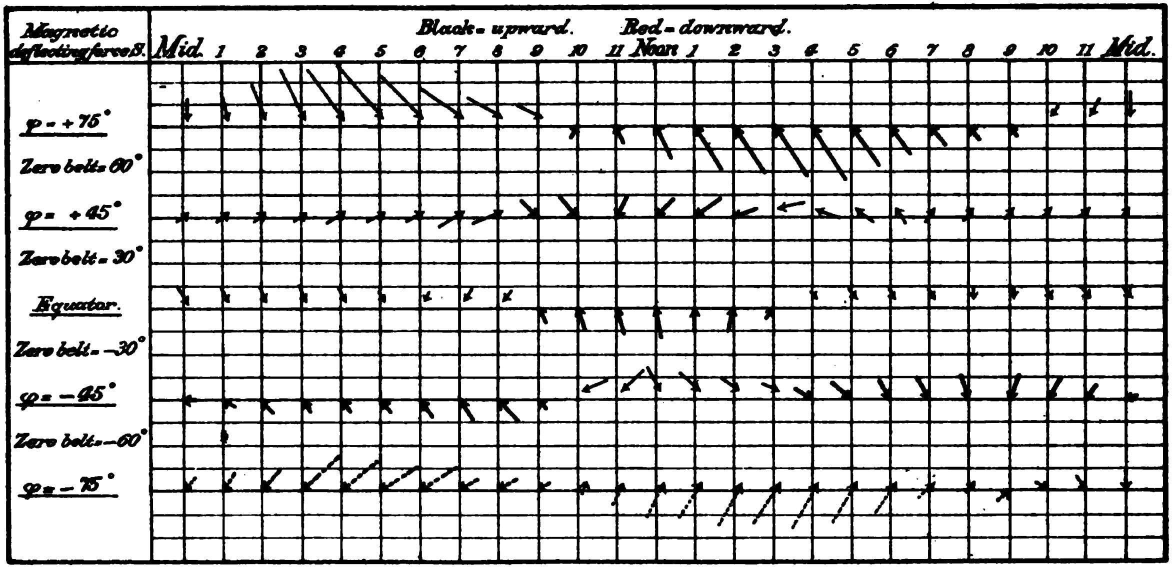

TABLE 25.—*The mean deflecting magnetic vector s at 26 stations distributed widely in latitude.*

[F. H. BIGELOW in Amer. Journ. Sci., August, 1895.]

I.

No	Station	Magnetic latitude	Year	Mean values								Adjusted values					
				South				North				South			North		
				β	α	s	σ	β	α	s	σ	s	σ	α	s	σ	α
		°												°			
1	Kingua Fjord	77.9	1882	161	+ 5	45	27	337	− 6	37	23	45	28	54	38	23	54
2	Fort Rae	76.0	1882	190	+ 8	46	30	5	− 8	39	22	53	29	55	43	24	55
3	Point Barrow	73.1	1882	180	− 6	59	29	4	+ 5	55	29	60	30	58	52	24	58
4	Cap Thordsen	71.1	1882	186	−14	62	28	6	+ 8	50	23	59	30	59	52	23	59
5	Jan Mayen	68.8	1882	180	+10	54	29	4	− 9	44	22	55	27	60	49	22	60
6	Bossekop	64.4	1882	188	+14	43	29	18	− 6	33	19	42	23	58	33	17	58
7	Toronto	62.2	1847	176	−28	32	18	356	+27	25	11	34	18	55	26	13	55
8	Sodankyla	61.4	1882	184	+ 5	16	15	14	− 2	14	12	31	15	54	24	11	54
9	Washington	55.6	1890	179	+19	18	7	357	0	20	8	20	12	48	14	8	48
10	Pawlowsk	55.1	1882	196	+10	12	10	15	− 9	10	8	18	10	47	13	8	47
11	Greenwich	50.4	1887	175	− 6	13	9	359	+ 1	13	9	14	9	43	10	7	43
12	Parc St. Maur	47.3	1884	177	+ 2	12	9	357	− 4	11	8	13	10	41	10	8	41
13	Vienna	44.8	1882	178	+ 5	19	15	1	− 1	20	16	14	11	40	11	9	40
14	Pola	41.7	1892	183	+14	23	16	1	− 6	17	11	16	12	38	12	9	38
15	Los Angeles	40.3	1883	181	+10	22	12	0	− 8	23	10	17	13	37	13	10	37
16	Tiflis	36.1	1882	182	+ 6	15	12	13	− 7	13	11	23	19	37	17	16	37
17	Zi-ka-wei	27.6	1882	187	− 4	42	32	351	+ 5	33	23	38	27	43	32	23	43
18	Bombay	9.9	1863	182	+ 4	36	20	3	− 5	33	16	31	20	53	25	15	53
19	Madras	3.8	1855	185	+ 2	13	11	349	− 1	12	10	19	14	36	15	11	36
20	Singapore	− 6.4	1845	182	− 2	14	11	359	− 8	12	10	15	11	39	11	8	39
21	St. Helena	−11.2	1843	178	−10	17	9	349	− 2	17	8	16	10	57	12	7	57
22	Batavia	−15.1	1890	182	+13	16	8	1	−12	16	9	22	12	58	15	8	58
23	Süd Georgien	−29.8	1882	187	+26	52	20	8	−17	47	15	36	19	47	31	16	47
24	Cape Horn	−33.5	1882	176	− 2	15	13	6	+ 4	13	10	25	13	44	19	10	44
25	Cape Good Hope	−33.9	1842	185	+16	19	11	353	− 3	16	11	20	12	43	15	9	43
26	Hobarton	−54.8	1842	176	+22	26	15	0	−27	22	13	26	14	52	22	12	52

β=magnetic azimuth, for north=0°, west=90°, south=180°, east=270°.

II. COMPARISON OF THE AZIMUTH ANGLES β AS COMPUTED BY BIGELOW AND VAN BEMMELEN.

Station.	βS	$\Delta\beta S$	βN	$\Delta\beta N$	Mean	β	Dec.	Bigelow β'_1	Bemm. β'_2	Difference $\beta'_2-\beta'_1$
Kingua Fjord	161	−19	337	−23	−21	159	N 72 W	231	207	−24
Fort Rae	190	+10	5	+ 5	+ 8	188	N 40 E	148	184	+36
Point Barrow	180	0	4	+ 4	+ 2	182	N 36 E	146	156	+10
Cap Thordsen	186	+ 6	6	+ 6	+ 6	186	N 13 W	199	220	+21
Jan Mayen	180	0	4	+ 4	+ 2	182	N 30 W	212	222	+10
Bossekop	188	+ 8	18	+18	+13	193	N 4 W	197	205	+ 8
Toronto	176	− 4	356	− 4	− 4	176	N 1 W	177	181	+ 4
Sodankyla	184	+ 4	14	+14	+ 9	189	N 1 W	190	198	+ 8
Washington	179	− 1	357	− 3	− 2	178	N 4 W	182	187	+ 5
Pawlowsk	196	+16	15	+15	+16	196	N 1 W	197	200	+ 3
Greenwich	175	− 5	359	− 1	− 3	177	N 18 W	195	198	+ 3
Parc St. Maur	177	− 3	357	− 3	− 3	177	....	....	....	....
Vienna	178	− 2	1	+ 1	− 1	179	....	....	....	....
Pola	183	+ 3	1	+ 1	+ 2	182	N 10 W	192	188	− 4
Los Angeles	181	+ 1	0	0	+ 1	181	....	....	....	....
Tiflis	182	+ 2	13	+13	+ 8	188	N 1 E	187	195	+ 8
Zi-ka-wei	187	+ 7	351	− 9	− 1	179	N 2 W	181	174	− 7
Bombay	182	+ 2	3	+ 3	+ 2	182	N 1 E	181	188	+ 7
Madras	185	+ 5	349	−11	− 3	177	....	....	....	....
Singapore	182	+ 2	359	− 1	+ 1	181	....	....	....	....
St. Helena	178	− 2	349	−11	− 7	173	N 23 W	196	168	−28
Batavia	182	+ 2	1	+ 1	+ 2	182	....	....	....	....
Süd Georgien	187	+ 7	8	+ 8	+ 8	188	N 0 W	188	188	0
Cape Horn	176	− 4	6	+ 6	+ 1	181	N 20 E	161	192	+31
Cape Good Hope	185	+ 5	353	− 7	− 1	179	N 29 W	208	167	−41
Hobarton	176	− 4	0	0	− 2	178	N 10 E	168	168	0

The second section of Table 25, " comparison of the azimuth angles β as computed by BIGELOW and VAN BEMMELEN," gives a summary of a paper by VAN BEMMELEN in Terrestrial Magnetism, September, 1900, on " The magnetic post purturbation and the current vortices of SCHMIDT." The geographical azimuth (β'_2) of the disturbing force at 28 stations is given, and these were computed from the large disturbances of selected days. In my table β is the magnetic azimuth and β' the geographical azimuth of the deflecting vector; β_S is the southward and β_N the northward value from the first section of the table; $\Delta\beta_S$ and $\Delta\beta_N$ are the differences between the magnetic and the line of 0°–180° azimuths; from the mean $=\frac{1}{2}(\Delta\beta_S+\Delta\beta_N)$ the average magnetic azimuth β is found. The declination is taken from Table 17, Bulletin No. 21, page 84, and the geographical azimuth β'_1 (BIGELOW) is computed. The next column β'_2 (BEMMELEN) contains his geographical azimuth. The difference $\beta'_2-\beta'_1$ shows that the two computations are in close agreement except for a few polar stations. This may arise from the fact that we have not employed the same data in the discussion, since my computations depend upon all the variations at the several stations throughout a year, and his upon the days of special disturbances. We conclude that the disturbing vectors cling closely to the magnetic meridians, and that the east-west component is very small. If VAN BEMMELEN should in a similar manner extend his computation to include the vertical force in the vector, we could then compare his result with the other values in the upper section of Table 25, or with Chart 10 of Bulletin No. 21. It is very desirable that other magneticians should construct such deflecting vectors for the different magnetic fields as was done in that report.

The adjusted vectors, Table 25, Section I, are plotted on figure 2, Chart 31, and they make a

CHART 31. **Comparisons of the magnetic and electric vectors in latitude.**

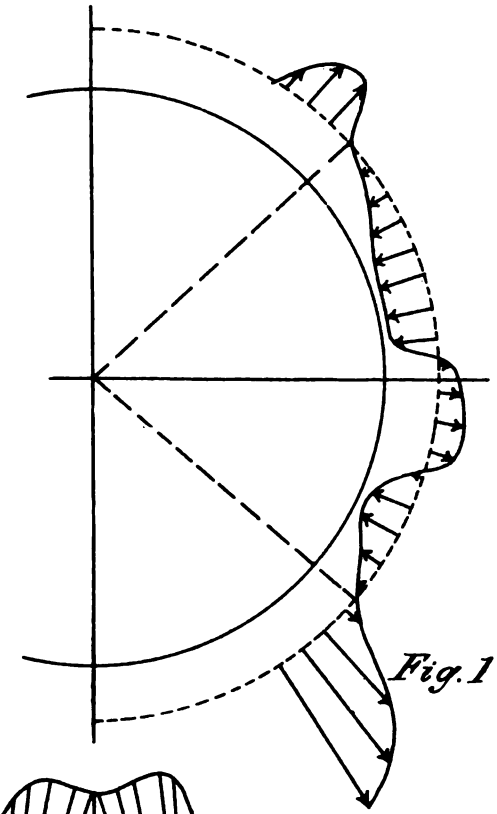

Fig. 1

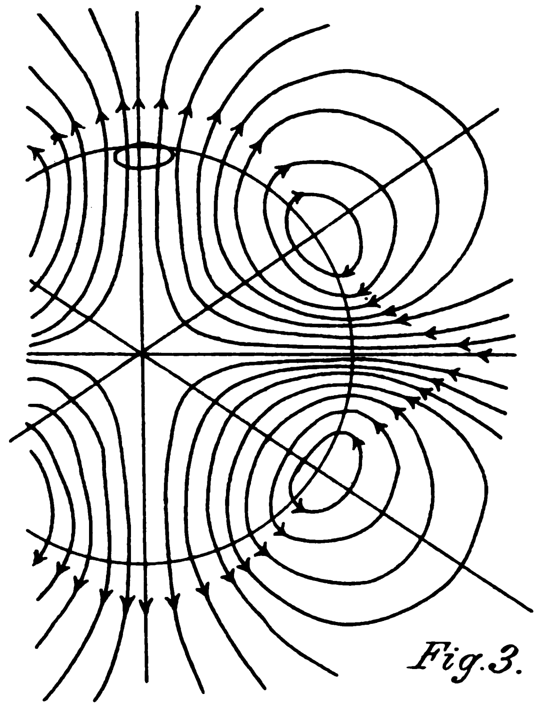

Fig. 3.

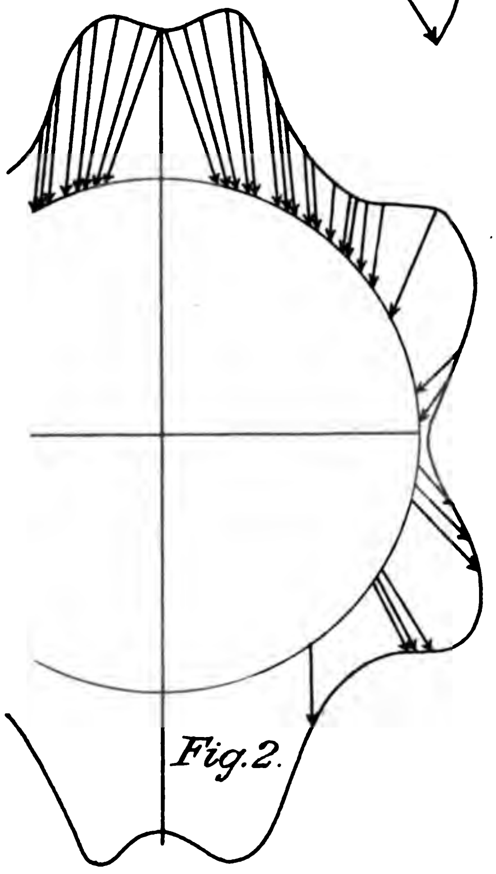

Fig. 2.

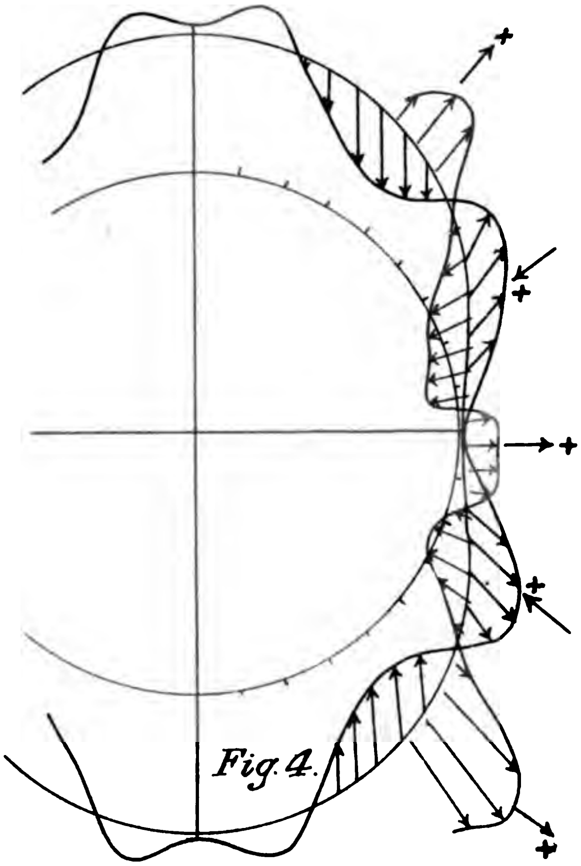

Fig. 4.

curve of intensity giving maxima at latitude 30° and 80°. This evidently differs from the theoretical intensity belonging to the distribution of force for a permeable sphere placed in an external field. The direction of the vectors was explained by assuming that the earth too acts like a permeable shell (pp. 70–71), and the theoretical diagram matches the computed vector directions so closely as to give occasion to further remark in this place. The intensity of the vector system has been noted by Professor **Schuster** to differ from the theoretical form, and he infers that this is an argument against the general theorem to which I ascribed the phenomenon. However, by computing the normal magnetic curve from the formulæ given in Table 26, "The relative intensity of the magnetic force induced on a permeable sphere or shell when immersed in an external field," we have the curve shown in the noninflected curve of Chart 31, figure 4. This computed system is superposed upon the vector system derived from the observations, and gives the comparison of the computed and observed vectors in latitude. The differences between these two vector systems consist of residuals in which the normal field shows an excess over the observed field from near the pole to about latitude 40°, and a defect between latitude 40° and the equator, the same being true in both hemispheres. Any physical principles which account for the superposition of these secondary or residual magnetic vectors upon the primary vectors produced by placing the earth as a magnetic sphere, positive pole in the southern hemisphere and negative pole in the northern hemisphere, within the sun's external magnetic field, positive on the northern side of the eliptic and negative on the southern side of the eliptic, are competent to remove this objection against the theory advanced to account for the phenomenon Hence it would follow that if there is reason for the existence of this secondary field as a disturbance, its superposition upon the normal external field, so far from being an argument against the sun's magnetism, as was assumed, becomes very powerful evidence in its favor. Indeed, it seems to me that this feature of the magnetic field at the earth, taken in connection with the phenomenon of the stripping of the polar regions of the sun of all coronal rays, constitutes nearly a proof

Table 26.—*Relative intensity of the magnetic force induced on a permeable sphere or shell when immersed in an external field.*

[Formulæ—Bulletin 21, p. 67.]

$$F_n = X\cos\theta + Y\sin\theta = \frac{4}{3}\pi R^3 I\cdot\frac{2\cos\theta}{r^3} = \frac{4}{3}\pi R^3 I\frac{2x}{r^4} = -F_i\frac{R^3}{r^3}\cdot 2\cos\theta = \frac{4}{3}\pi I\cdot 2\cos\theta$$

$$F_t = -X\sin\theta + Y\cos\theta = \frac{4}{3}\pi R^3 I\cdot\frac{\sin\theta}{r^3} = \frac{4}{3}\pi R^3 I\frac{y}{r^4} = -F_i\frac{R^3}{r^3}\cdot\sin\theta = \frac{4}{3}\pi I\cdot\sin\theta$$

For the surface $R=r$ $\quad -F_i=\frac{4}{3}\pi\,.\,I$ $\quad$ Assume for type, $\frac{4}{3}\pi\, I=$unity.

Polar distance	$2\cos\theta$ $=F_n$	$\sin\theta$ $=F_t$	$\tan\alpha$ $=\frac{F_n}{F_t}$	α	$\left(F_n^2+F_t^2\right)^{\frac{1}{2}}$ $=F$	s
$\theta=$ 0	2.0000	0.0000	∞	90.0°	2.00	.00040
10	1.9696	0.1736	11.30	85.0	1.98	40
20	1.8794	0.3420	5.49	79.7	1.91	38
30	1.7320	0.5000	3.46	73.9	1.80	36
40	1.5320	0.6428	2.38	67.2	1.66	33
50	1.2856	0.7660	1.68	59.3	1.50	30
60	1.0000	0.8660	1.16	49.3	1.32	26
70	0.6840	0.9397	0.73	36.2	1.16	23
80	0.3472	0.9848	0.35	19.3	1.05	21
90	0.0000	1.0000	0.00	0.0	1.00	.00020

positive that the sun is a strongly magnetized sphere, as supposed in my original report. The maximum strength of this secondary field at latitude 60° is 0.00020 C. G. S., and at latitude 30° it is 0.00015 C. G. S. There is a slight maximum near the pole in the region of the middle of the auroral belt, which I shall neglect for the sake of not complicating the main purpose of this inquiry.

TABLE 27.—*Vertical earth-air electric currents.*

[L. A. BAUER, Terr. Mag., March, 1897.]

$+$ = upward electric current; $-$ = downward.

Units	ΣY_e C. G. S.		I 10000 amp.		ΔI 10000 amp.		i 1 amp. per sq. km.			i C. G. S.
Latitude	N	S	N	S	N	S	N	S	Mean	Mean
60	+.0271	+.0992	+ 60	+219						
					+ 42	+326	+.035	+.274	+.154	+.01540
55	+.0401	−.0422	+102	−107						
					+141	+303	+.104	+.224	+.164	+.01640
50	+.0856	−.1445	+243	−410						
					+135	+238	+.091	+.159	+.125	+.01250
45	+.1213	−.2078	+378	−648						
					− 20	+ 37	−.012	+.023	+.006	+.00060
40	+.1057	−.2022	+358	−685						
					− 32	− 39	−.018	−.022	−.020	−.00200
35	+.0900	−.1784	+326	−646						
					− 66	− 76	−.035	−.040	−.038	−.00380
30	+.0680	−.1489	+260	−570						
					−118	−151	−.060	−.077	−.068	−.00680
25	+.0381	−.1048	+142	−419						
					−132	−175	−.064	−.085	−.074	−.00740
20	+.0023	−.0587	+ 10	−244						
					−166	− 64	−.079	−.030	−.054	−.00540
15	−.0366	−.0422	−156	−180						
					−155	+ 58	−.072	+.027	−.022	−.00220
10	−.0714	−.0547	−311	−238						
					−185	+ 97	−.084	+.044	−.020	−.00200
5	−.1128	−.0762	−496	−335						
					+ 79	+ 82	+.136	+.037	+.036	+.00360
Equator 0	−.0944	−.0944	−417	−417						
										.00160

L. A. BAUER published in Terrestrial Magnetism, March, 1897, an account of his research into the line integral of the magnetic force along the parallels of latitude, at 5° intervals, the components being ultimately derived from NEUMAYER's Charts. He recognizes the possible imperfections inherent in such data, and yet reaches a result so symmetrically disposed as to suggest interesting physical conditions in the earth's magnetic field. Table 28 is taken from Dr. BAUER's paper, and, together with figure 1, Chart 31, shows the result. $\Sigma Y_e = \Sigma H \cos \varepsilon =$ the summation of the easterly components, as constructed for each degree of longitude; $I =$ the resultant or the total quantity of electricity passing in the unit time, perpendicular to the surface of the earth, through the zone between the parallel of latitude and the pole, expressed in units of 10,000 ampères; $\Delta I =$ the part in the narrow zones 5° wide; $i =$ the corresponding electric vertical earth-air current in amperes per square kilometer; the last column gives the mean value of i in C. G. S. electro-magnetic units. For the sake of comparison with the magnetic secondary vectors, the electric vectors of figure 1 are plotted on the mean magnetic curve of the primary field in figure 4, Chart 31, and they are shown in red. It is noted that they agree in representing a very similar distribution of force, though of course not comparable with each other superficially, since the black secondary vectors represent magnetic force and the red vectors electric current. The turning points and the location of the maxima are nearly identical, except that BAUER has some small vertical currents just south of the equator. This approximate agreement of two systems of forces can hardly be considered accidental, and it gives ground for believing that each of them stands for physical realities.

In order to consider the proper mode of explaining the existence of these two vector systems, I shall introduce a few extracts from papers dealing with the question. Dr. AD. SCHMIDT's conclusion regarding his computation on the terrestrial magnetic field is well known to be as follows (Neue Berechnung des Erdmagnetischen Potentials, 1895):

> The empirically determined distribution of the earth's magnetic force at the surface, as it is represented by Dr. NEUMAYER's charts for the epoch 1885.0, depends for the most part upon causes which have their seat within the earth, but it can not be exclusively referred to such. A small part of the force, about one-fortieth of the whole amount, is to be ascribed to sources outside the earth's surface; another, somewhat larger part, which is equivalent to a current of about one-sixth ampère on an area of 1 square kilometer, should be referred to electric currents which traverse this surface.

The first and second components have a potential, while the third has no potential, but is assumed to be induced by electric currents. Dr. BAUER refers his vectors to a closed system of electric currents, such as HERTZ deduces for a magnetic sphere rotating in a conducting medium. The proposition as stated by HERTZ is as follows (H. Hertz, Induction in Rotating Spheres, "Miscellaneous papers," p. 107):

> When a sphere of any arbitrary magnetic properties rotates in a liquid, which is itself a conductor, and makes electric contact with the surface of the sphere, the sphere will induce currents in the liquid. In general these no longer flow in concentric shells, but traverse the magnet. The form of the lines of flow does not depend upon the resistances of the magnet and the liquid. But the intensity vanishes when either resistance becomes infinitely great.

L. A. BAUER (Terr. Mag., March, 1897) comments as follows:

> (Page 17:) In their general nature, it will be seen that the currents resemble the electric currents resulting from the rotation of a magnetic sphere in a conducting fluid.
>
> (Page 20:) For the present, then, and until further investigations are made, it is useless to ask ourselves the question whether the vertical currents are the result of the rotation of the magnetized earth, with reference to the ether outside, or whether they are due to the differential rotation of the earth and atmosphere which takes place in consequence of the huge atmospheric whirls about each pole.

Prof. A. SCHUSTER (Terr. Mag., January, 1896) had already remarked:

> (Page 12:) It is seen that it would take 125 centuries to lengthen the day by 1 second. Small as this effect seems to be, it could not have escaped the notice of astronomers, for the earth as a timekeeper would lose 2.6 minutes in a century. This would limit us to a possible couple about six times smaller than the maximum, and hence if space had a conductivity either smaller than 5×10^{-16} or greater than 10^{-11} the effects as regards the lengthening of the day would be inappreciable.
>
> (Page 13:) Our calculation has proceeded on the assumption of a uniform conductivity of space. The reactions must always be such as to cause an induced potential displaced in the direction of rotation as compared to the inducing one.
>
> (Page 14:) The combined effect will be a tendency to shift the magnetic axis, in a direction opposite that of a sphere's rotation, round the axis of rotation and at the same time toward it. In whatever way the sphere was originally magnetized, the magnetic axis and the axis of rotation would ultimately tend to coincide.
>
> (Page 16:) If we could adopt Dr. SCHMIDT's numbers as final, they would show that the outside magnetic potential is displaced toward the east. Such an effect might be produced by currents induced in a medium rotating more rapidly than the earth, which might be the case if the upper currents of the atmosphere had a general drift from west to east. The displacement of the outside potential, according to Dr. SCHMIDT, is, however, greater than 90°, which is difficult to reconcile with the hypothesis of induced currents under any circumstances.

The following objections must, therefore, be interposed to the idea of accepting BAUER's theory to account for his electric vectors: (1) The conductivity of the ether is far too small, even admitting that anything of the kind exists in its normal state—that is, when under no strain of disruptive electric forces—to give the electric currents required by such induction; for if the conductivity is zero the electric forces vanish. (2) The conductivity of the atmosphere is also much too small to generate the electric vectors by the differential rotation of the atmosphere and the surface of the earth, as already shown by the preceding experiments of ELSTER and GEITEL; also, the atmospheric relative motion is not in one direction, such as the HERTZ induction requires, but it is eastward in the higher latitudes and westward in the tropical regions, except at very high altitudes, and this would necessarily produce a very different distribution of the induced currents from those here required. (3) Dr. A. W. **Rucker** in describing **Bauer's** result says (Nature, December 16, 1897):

> If the immediate surroundings of the earth are electrically conducting, the mere rotation of the huge magnetic mass of the earth itself would cause the production of currents which at some points would flow out of, and at others would flow into the surface.

This ascribes the effect to an electrically conducting ether, but conductivity of the ether is denied by most physicists, though there are some who advocate the possibility of such a property existing to some degree in the ether.

On the other hand, **Trabert** (Meteorol. Zeits., November, 1898) in discussing the subject does not refer to **Bauer's** analogue of the **Hertz** rotating sphere, but tries to show how similar electric currents are probable by the merely *mechanical convection* of charged masses in the several latitudes of the earth; while **Elster** and **Geitel** (Terr. Mag., March, 1899) in reviewing **Trabert's** paper prefer the theory of ionization, which has been explained in the preceding pages, to account for the phenomenon of the induced electric currents, and they do not mention the theory of induction by rotation. (4) The several attempts to verify the **Schmidt** theory of earth-air electric currents by taking line integrals on small regions of the earth where the magnetic surveys have been most minute and accurate have practically failed. Thus, **Rucker** in England, von **Bezold** in Germany, **Carlheim Gyllensköld** in Sweden, and **Liznar** in Austria, have each found the line integrals in all cases well within the limits of the probable errors of the surveys. All these results indicate that (1) there is no conductivity of the ether worth considering as a source of induction of electric currents, and (2) that such as does exist is probably the meteorological effect of solar radiation through ionization and the allied processes.

We can account for our residual vectors, in part at least, by applying the vector formula, $\mathbf{h} = V.\,\mathbf{Dq}$, where $\mathbf{h}$ is the magnetic force produced by the motion $\mathbf{q}$ of the medium containing an electric displacement $\mathbf{D}$, and is directed at right angles to the plane $\mathbf{Dq}$ in the right-hand rotation; this motion is a direct cause for the secondary magnetic vectors of figure 4, Chart 31. Thus the $\mathbf{D}$ lines are positive from the upper strata of the atmosphere towards the earth, which is negative, and the motion $\mathbf{q}$ is eastward in the latitudes from the poles to about ±35°, and westward in the tropical belt. Beginning in the southern or positive hemisphere, we find the first group $\mathbf{h} = V.\,\mathbf{Dq}$ directed northward, the second group southward; in the northern or negative hemisphere the counterpart groups are oppositely directed. This shows that we have a system of magnetic forces acting in the right direction, and if they are not large enough to entirely account for the residuals by themselves, they will yet guide all the other sources of energy otherwise produced towards the same directions, and so tend to sum them up altogether.

FURTHER EVIDENCE OF A CHARACTERISTIC DISTRIBUTION OF ENERGY IN LATITUDE FROM METEOROLOGICAL DATA.

In order to see whether any evidence of a similar meteorological distribution of energy in latitude exists, the following compilations have been made. The values of the vapor tension in latitude, expressed in millimeters, have been collected together from the Report on the Barometry of the United States, from those of the International Polar Expeditions, from numerous reports in the Tropics and in the southern hemisphere, and they are platted on Chart 32, figure 1. For temperature the **Ferrel** formula has been expanded to five terms, and it represents the mean annual temperature distribution in latitude quite closely. The computation is given in Table 28, and the result is platted on figure 2. The magnetic distribution, and by implication the atmospheric electric current distribution, is transferred to figure 3 of Chart 32 from figure 4 of Chart 31. It is seen that these elements all have a secondary minimum in the middle latitudes. In the case of the temperature it is the harmonic term $-20.95 \cos 2\theta$ which is the chief representative of the secondary variation, though the fourth and the fifth terms contribute to it. The distribution of pressure has not been reproduced here because this is so largely an effect of the dynamical forces of the general circulation as to be somewhat too complicated for this special purpose.

CHART 32. Variation of the vapor tension, temperature, and magnetic deflecting force, in latitude.

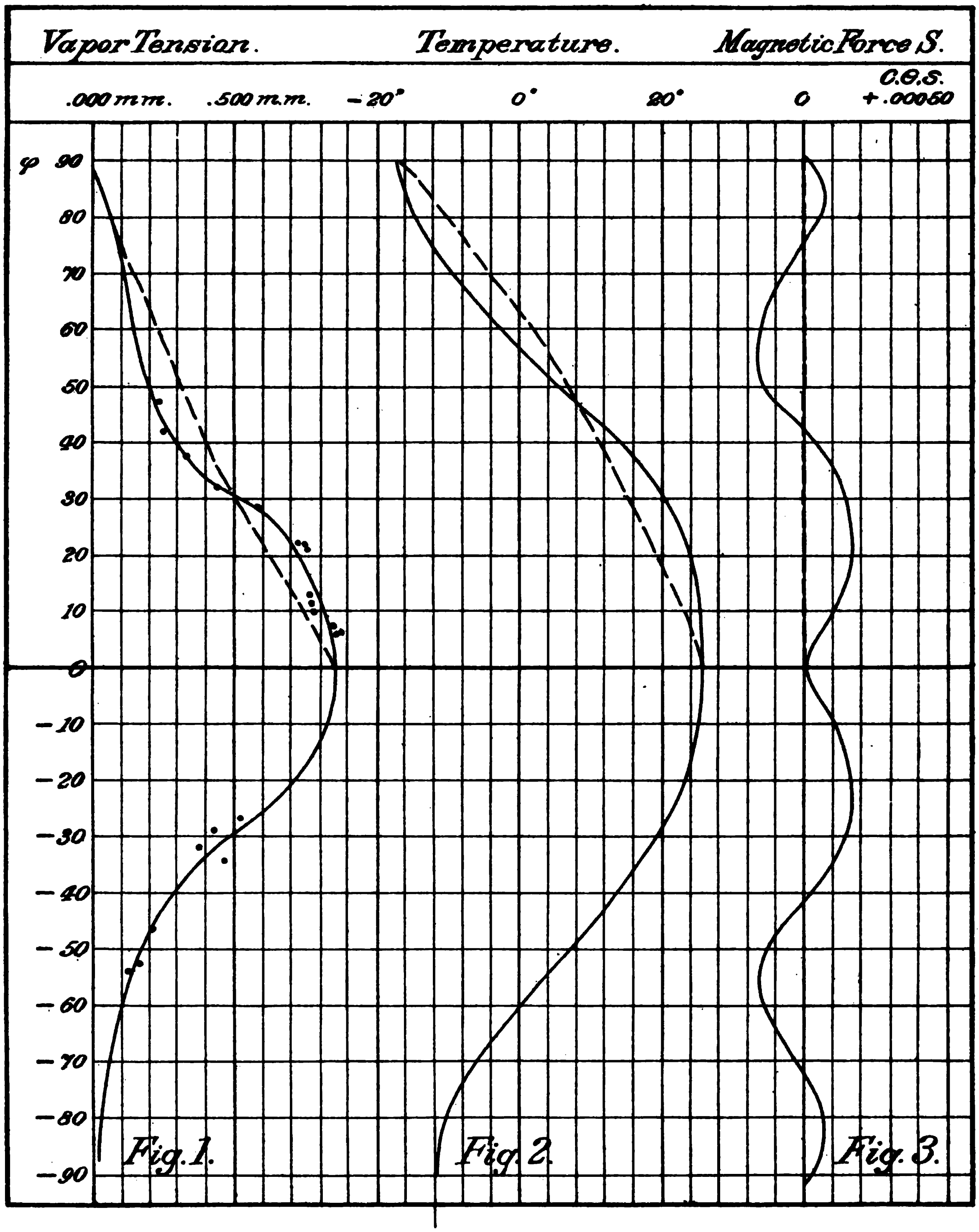

Table 28.—*Distribution of temperature in latitude.*

$t = \Sigma A_s \cos s\theta$ = Ferrel's formula. θ = North polar distance.

$A_0 = 8.50$ $A_1 = -1.75$ $A_2 = -20.95$ $A_3 = -1.00$ $A_4 = -2.66$

	cos 0° = 1	cos θ	cos 2θ	cos 3θ	cos 4θ	Sum
θ = 0	1.000	1.000	1.000	1.000	1.000	
10	1.000	.985	.940	.866	.766	
20	1.000	.940	.766	.500	.174	
30	1.000	.866	.500	.000	−.500	
40	1.000	.766	.174	−.500	−.940	
50	1.000	.643	−.174	−.866	−.940	
60	1.000	.500	−.500	−1.000	−.500	
70	1.000	.342	−.766	−.866	.174	
80	1.000	.174	−.940	−.500	.766	
90	1.000	.000	−.100	.000	1.000	
NORTHERN HEMISPHERE						
θ = 0	8.50	−1.75	−20.95	−1.00	−2.66	−17.86
10	8.50	−1.72	−19.65	−0.87	−2.04	−15.78
20	8.50	−1.64	−16.01	−−0.50	−0.46	−10.11
30	8.50	−1.52	−10.45	0.00	+1.33	− 2.14
40	8.50	−1.34	− 3.63	+0.50	+2.50	+ 6.53
50	8.50	−1.13	+ 3.63	+0.87	+2.50	+14.37
60	8.50	−0.88	+10.45	+1.00	+1.33	+20.40
70	8.50	−0.60	+16.01	+0.87	−0.46	+24.32
80	8.50	−0.30	+19.65	+0.50	−2.04	+26.31
90	8.50	0.00	+20.95	0.00	−2.66	+26.79
SOUTHERN HEMISPHERE						
100						+26.0
110						23.8
120						20.2
130						14.9
140						8.2
150						+ 0.9
160						− 5.8
170						−10.6
180						−12.4

CONCLUSIONS.

In general it is noted that the secondary vector systems do harmonize with the main features of the circulation over the entire globe. At the same time the physical processes of convection and ionization also are similarly distributed into two great systems, so that both are intimately associated together. Taking this survey in latitude together with the survey in longitude as revealed in the diurnal variations, it must be conceded that the meteorological, electric, and magnetic forces are bound up closely together, in such a way that they must be explained by the action of one source of energy working so as to produce these several manifestations in the atmosphere. Trabert, Elster and Geitel have attempted to trace the connection between the observed variations in the electric displacement gradient for the several latitudes, showing that the cloud belts in the tropics are favorable for electrical currents from the air to the earth, while the two belts of the temperate zones and the equator belt are favorable for currents from the earth to the air, the latter being positive and the former negative. There is, however, no little difficulty in arriving at quantitative results, owing to the imperfection of the observations of the upper atmosphere of nearly all the quantities concerned. Hence, in place of endeavoring to carry the research further at this time, it is better to postpone it to another occasion for a more critical study of the complex physical problems. The physical processes in the atmosphere, involving the magnetic, electrical, and meteorological elements, are without doubt very complex, so that it is not easy to specify exactly how each system reacts upon the others. As regards the cause of the diurnal deflections of the normal magnetic field the following suggestion is offered: If in a given space under entirely normal conditions, which shall be those represented by the mean values for the day, the radiation of the sun enters, the following course of events may take place. As the result of ionization and drainage from a given space of a relatively large number of the negative ions, it is now occupied by a greater number of isolated positive electric charges than before the event. If in the neighboring spaces similar effects take place, but differing quantitatively, it is evident that a new system of electrical repulsions is set up which acts upon the environment. When such differential effects are extended to the entire atmosphere, in the proportion indicated by the diurnal curves, there is caused practically a bodily displacement of electrical energy extending to the whole atmosphere. We have seen that magnetic force is able to deflect the rays of charged particles; also, the electrostatic force is able to do the same thing; the particles move in paths which are at right angles to the magnetic lines but parallel to the electric lines. It is, therefore, quite probable that the ionization of the atmosphere is the cause of the change in the magnetic field, just as much as it is the cause of the change in the electrostatic field. For by it the number of positively charged ions in a unit volume is changed from the normal number, and, if this volume is traversed by weak magnetic lines, it is to be expected that the disturbance will extend to the magnetic field so as to produce a change in the direction and the intensity of the vector. Should this prove to be the fact, we escape from the difficulties connected with attributing the deflecting magnetic vectors to the meteorological circulation, or to the feeble electric currents possible in a nearly nonconducting medium. This indirect action of the solar electro-magnetic field in producing results quite like those which a purely polar magnetic field in its place would cause, is doubtless a more correct description of that phenomenon than the one mentioned in Bulletin No. 21, though the outcome is quite the same for practical purposes. It seems to be as important to understand the exact action of an increase in the number of the ions upon the magnetic field, as that of a magnetic field in deflecting the course of an ionized ray. This can probably be accomplished by laboratory experiments, if it has not already been done.

In glancing backward over the suggestive series of facts that have been brought together as the result of recent physical researches, it seems to be justifiable to remark: (1) The probability that the sun is a strongly magnetized sphere embracing the earth within its field is decidedly increased by the theory of the solar corona as an appendage of electrically charged minute particles of matter, or ions, which are excluded from the polar zones and are distributed along the magnetic lines of force, especially at times of minimum solar activity; and by the view that the corresponding solar magnetic field at the earth is resolvable into two portions—one strictly solar in origin and the other generated within the earth's atmosphere by ionization and allied physical processes. (2) The problems pertaining to the meteorologist must in consequence of this result include a description of the magnetic field as well as the electric field in the atmospheres of the sun and the earth, together with the processes relating to the variation of pressure, temperature, vapor tension, and the circulation of the air. Especially, efforts should be made to measure the magnetic and the electric potentials in the higher strata of the free air, because upon a definite knowledge of them in that place our elucidation of many problems depends. (3) Since the motions of the air depend ultimately upon the effects of solar radiation, and these upon solar activity, it is plain that a thorough examination of the solar polar magnetic and electromagnetic fields should be prosecuted in the interests of general forecasting.

UNIPOLAR DISSIPATION OF NEGATIVE ELECTRICITY IN POLAR LOW ELEVATIONS AND IN TROPICAL HIGH ELEVATIONS.

In the February (1901) number of the Meteorol. Zeit., J. **Elster** gives an interesting account of his measures of the coefficient of the dissipation of electricity in the free atmosphere at different latitudes from Algiers to Spitzbergen. The apparatus used is that described in Terr. Mag., IV, 213, Dec., 1899; also he used an **Exner** apparatus for measures on the potential gradient, which he found to range between 30 and 100 volts per meter. Generally the rate of dissipation of electricity increases with the clearness of the atmosphere, and decreases with the increased amount of the causes of obscurity, such as dust, fog, mist, etc. The negative electricity dissipates faster than the positive electricity; the rate increases with the altitude above the sea level, because the air is clearer; the wind has no effect upon the rate of dissipation; the rate of dissipation does not depend upon the latitude; the conductivity of the air is less in continental than in ocean climates. All these phenomena are measures of the relative freedom of the air from dust and other causes of opacity.

A peculiar fact was, however, brought out, namely, that the conductivity of the air for negative electricity increases faster than for positive electricity with the latitude, so that in Spitzbergen the negative electricity dissipates two or three times as fast as the positive, whereas in Algiers the rate is about the same. This same fact is also found to prevail at high altitudes in low latitudes, so that we may infer that the phenomenon of increased dissipation of negative electricity begins at the ground in the north polar latitudes, follows a surface which arches high over the tropical latitudes, and descends again near the south polar regions. In this respect the polar regions and the elevated tropical regions are more favorable for the conduction of negative electricity than for positive. We also note that this arching surface outlines the region within which the vapor contents of the atmosphere are for the most part confined, the low polar and the high tropical strata being very dry, on account of the dependence of aqueous vapor upon the temperature of the air, since at low pressures the absolute vapor content is very small. Also it is found from the balloon ascensions in middle latitudes that the region of the phenomenon of active atmospheric electricity is confined to about 5,000 meters, as shown by the disappearance of the potential gradient. In a word, the presence of electricity is largely associated with the vapor contents of the atmosphere. Since ionization by solar radiation seems to be the cause of the electric potential fall, we think it must be derived from the effect of this action specifically upon the aqueous vapor of the atmosphere. The unipolar dissipation, when it goes so far as to be pronounced, is a means of marking the upper boundary of the locus of the activity of the vapor tension; also, the ratio of $\frac{a_-}{a_+}=q$, the rate of dissipation of the negative to the positive electricity, may be used to draw similar curved surfaces or arches through the atmosphere from the polar to the tropical regions, and thus map off the atmosphere according to this property of it. I have introduced this point to emphasize the intimate dependence between the magnetic forces operating in the polar regions, as in the aurora, and the presence of the negative electricity there, for which it has a special affinity. The fact that it is the negative electric discharge in vacuum tubes and cathode radiation generally which is deflected by the magnetic field is in harmony with the idea that these two fields of force interact upon one another in the atmosphere, because an increase in negative electricity must deflect a normal magnetic field just as much as an increase in a magnetic field must deflect a mass of negative ions.

H. **Ebert** has succeeded in measuring the coefficients of dissipation of the positive a_+ and the negative a_- electricity in balloons soaring at considerable heights, with the result that the unipolar character of the electricity seems to disappear in the free air at moderate distances above the ground, since q is nearly equal to unity, i. e., $q=\frac{a_-}{a_+}=1$.

DEFLECTION OF THE EARTH'S MAGNETIC AND ELECTRIC FIELDS BY A CHANGE IN THE AMOUNT OF THE SOLAR RADIATION.

It has been sought by many magneticians to escape from the difficulties of the theory of the direct magnetic action of the sun upon the earth through a curved or polar field by an appeal to the hidden potentialities of the solar radiation, especially the invisible waves of shorter length than those seen in the visible spectrum. It is evident that in order to account for the multitude of variations observed in the earth's magnetic field there must be equivalent variations in the solar radiation on both sides of the normal. This view will, however, probably break down before the two following facts: (1) That no variations in the solar radiation have been detected corresponding to those in the magnetic field, although the shifting of the solar lines has been carefully studied; and (2) that the large disturbance variations do not come from the same vector field as the diurnal variations, but generally from a vector field lying athwart it. Thus it is found that when a violent disturbance is taking place with a wide deflection of the normal field, the diurnal system of component vectors is transformed hour by hour into that of the polar field which carries the disturbing vectors. This is just opposite to what would be the case if an intensification of the solar radiation is the true cause of the great disturbance vectors, as distinguished from the diurnal vectors. Till these two objections are removed, the hypothesis of a variable action in the radiant field is merely a conjectural view.

We have, however, two distinct examples of the effect of a change in the radiation upon the diurnal components. (1) The change from day to night, when the solar radiation is changed from its maximum to a total withdrawal, is an example of what variation can be made by that source of difference. In no case is it found to produce the system of polar magnetic disturbances, which are directed closely along the magnetic meridians, as stated above in Table 25. A comparison of Chart 30 with Charts 29, 31, and 32 is sufficient comment upon this statement.

We have, moreover, in Dr. L. A. BAUER's observations on the eclipse of May 28, 1900,* a second example of such action. It is shown that during the withdrawal of the sunlight in part or wholly during the passage of the shadow there was a small but distinct variation in the elements of the magnetic field, which must be attributed to that cause. The variations are all feeble, but apparently distinct enough to be of consideration. The time of the duration of the oscillation was about the same as that of the eclipse; the total range of the oscillation was about one minute in arc for the declination and about 0.00008 C. G. S. for the horizontal component; the effect was to deflect the declination needle westward before but eastward after the totality; to decrease the horizontal intensity before and to increase it after the maximum obscuration; the vertical intensity decreased at the time of totality; the cause is apparently outside the earth's surface and it moved along the belt of totality, lagging somewhat behind the moon's shadow; this oscillation is to be referred, probably, to some change produced in the upper regions of the atmosphere by the temporary withdrawal of the sun's rays through the interposition of the moon's body.

Furthermore, J. ELSTER observed in the same eclipse at Mustapha, Algiers, the potential fall in volts during the passage of the shadow, and found that a minimum voltage occurred at the time of the totality. (Terr. Mag., September, 1900, p. 127.) R. LUDEWIG (Beiblätter 23, p. 857, 1899) observed the same fact of a minimum of the electric potential in the eclipse of January 22, 1898.

All these facts taken together show that the solar radiation is able to simultaneously change the magnetic force and the electric force in the atmosphere, and this is in itself a direct confirmation of the view advocated in this report. (Compare also "The magnetic theory of the solar corona," by FRANK H. BIGELOW, Amer. Journ. Sci., April, 1901.) If we refer them to the theory of ionization in the atmosphere, as explained above, we have a chain of physical causes and effects which is so clear and probable that we may expect to find further confirmation of its truth in other directions.

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*Résumé of magnetic observations made chiefly by the United States Coast and Geodetic Survey on the day of the total solar eclipse, May 28, 1900. By L. A. Bauer: Terr. Mag., December, 1900.

Arrhenius proposes the view that the ions generated in the sun are propelled by the pressure of the electromagnetic radiation outward into planetary spaces, and at the planets and comets cause the well-known types of radiation. But it is evident that the comet tail is a radiation beginning at the head itself, and so is caused by the formation of ions in the nucleus of the comet instead of by ions transported from the sun. At the earth the "Gegenschein" is a planetary tail on the side of the astmosphere distant from the sun, and therefore it is an effect of the ions produced in the atmosphere which trail off into space. It seems to me more probable that the sun's radiation produces these ions *in situ* in the gases of the upper strata of the earth's atmosphere than that they are propelled to the earth from the sun, and I have preferred to consider the other attendant phenomena from this point of view rather than from that suggested by Arrhenius.

CHAPTER 5.

FUNDAMENTAL PHYSICAL RELATIONS.

GENERAL REMARKS.

It must be evident from an examination of the contents of Chapter 4 that the higher meteorology of the future will deal vigorously with the fundamental physical relations which are involved in electricity and magnetism, radiation, and the spectrum analysis. It has seemed to me desirable to prepare a brief synopsis of the most important of the mathematical equations for the sake of ready reference by students of these subjects. The works of Oliver Heaviside, J. J. Thomson, and H. Hertz are especially valuable in this connection, and they are, in many respects, fundamental in modern science. Heaviside and Hertz have brought together the duplex relations of electricity and magnetism, while Thomson has made important advances in the physics of matter. Thomson has followed closely in the steps of Maxwell in his method of analysis, while Heaviside has developed a new symbolic system of some obscurity to superficial readers, but in reality of great power and value in the advancement of science. There has been difficulty in securing the attention of students familiar with the Maxwellian system, and persuading them to use Heaviside's notation, but it is clear that the latter work is held in higher favor now than it was some years ago. I have attempted to assist the transition from one system to the other by exhibiting plainly in one common notation the corresponding quantities, especially in the elementary equations. Heaviside uses the terms scalar, vector, vector potential, potential slope, divergence, curl, circuitation, etc., in their defined sense, and operates with them freely through the most complex conditions. It would not be possible to carry the Maxwellian coordinate system through these changes without the utmost complexity and even confusion in the mathematics.

Heaviside differs from other authors chiefly by introducing the use of a system of units which gives *one line* of force from a unit pole instead of 4π *lines.* The common system makes the squared unit of length, as one square centimeter, the unit area, and the force falling upon it from the pole the unit; this would make 4π units pass through the spherical surface surrounding the pole. The difference comes to this, shall we use a plane square area as the unit or the spherical area at the same distance from the pole? The common system is so firmly embedded in our mathematics that it has become very hard to dislodge it, even in a good cause, and I suspect that the two systems must live together as best they may for some time to come. The advantages of the unit system, as used by Heaviside, are very considerable, and I have tried in some respects to bridge the gap between the systems by indicating with a parenthesis (4π) in the fundamental Tables 29 and 30 the place that 4π should have in order to reduce the Heaviside system to the common system. This plan is, however, dropped after the equations in Table 32, from which point the Heaviside system prevails without modification. In Table 34, Symbolic Operations, the symbols $\overset{|}{\Sigma}$ (line) $\overset{||}{\Sigma}$ (surface) $\overset{|||}{\Sigma}$ (volume) for summation have been used for the ordinary $\left(\int\cdot\int\int\cdot\int\int\int\cdot\right)$ symbols of integration. It is desirable to study these subjects in the following texts in order to arrive at a working knowledge of these tables:

1. Electromagnetic Theory, by O. HEAVISIDE.
2. Electrical Papers, by O. HEAVISIDE.
3. Recent Researches in Electricity and Magnetism, by J. J. THOMSON.
4. Elements of Electricity and Magnetism, by J. J. THOMSON.
5. Electricity and Magnetism, by JAMES CLERK MAXWELL.
6. The Mathematical Theory of Electricity and Magnetism, by WATSON and BURBURY.
7. The Theory of Electricity and Magnetism, by A. G. WEBSTER.
8. Electrical Waves, by H. HERTZ.
9. Maxwell's Theorie der Electricität und des Lichtes, von L. BOLTZMANN.
10. Physik des Aethers, von PAUL DRUDE.
11. Électricité et Optique, par H. POINCARÉ.
12. Magnetische Kraftfelder, von H. EBERT.

It may be noted that in the first volume of HEAVISIDE's electrical papers the 4π appears in the equations as it would in the common system, but that it is laid aside generally in the second volume and in the electro-magnetic theory. He seems to have made the transition by experience with his own system, but this fact makes it easy for others to follow the same process of transformation.

CONTENTS OF THE FOLLOWING TABLES.

Tables 29 and 30 give the fundamental relations in electricity and magnetism in the HEAVISIDE system, with the (4π) indicated for the common system. The duplex formation of the relations is carefully preserved in the symmetrical arrangement. Table 31 contains J. J. THOMSON's electro-magnetic system and notation. In Chart 33 are shown the mutual relations of the fundamental vectors. If the component proper to the axis is taken for each, as (X for E), (β for H), (w for C), then the construction of the following formula can be made without confusion of the primary relations. Table 32 gives the cross connections between electricity and magnetism as embodied in HEAVISIDE's laws of circuitation and the quantities derivable from them. Table 33 exhibits the equations of motion for nearly all possible mechanical relations, and also one of several possible mechanical analogues, though none of them are without objection. Table 34 gives a collection of symbolic operations, Table 35 some inverse operations, and Table 36 the relations between potential, slope, divergence, and curl. Table 37 contains several cases of magnetic fields caused by moving electric charges, and these are very useful in atmospheric discussions. Table 38 contains the notation and the most important equations in the papers by J. J. THOMSON and J. H. JEANS on the conductivity of electricity through gases by charged ions. Table 39 summarizes several papers written on the ZEEMAN effect. Table 40 gives the most important results of the theory of the shifting and broadening of spectrum lines by means of variations of the temperature, density, and pressure of the gases. Table 41 summarizes the radiation function in the spectrum. Table 42 contains the most important formulæ used in computing the heliographic positions of sun spots or other points on the sun.

I have tried to group these formulæ together in such a way that a student once familiar with the original papers may find the notation and the analytic relations in a convenient form for ready reference. The subjects of solar physics, meteorology, electricity and magnetism are so firmly interwoven together, that it has become a necessity to have some such helps in their study, unless their very magnitude is to prevent a broad and comprehensive knowledge of this great department of science. I have had the benefit of Mr. HEAVISIDE's correspondence in preparing the explanatory synopsis of his system.

EXPLANATORY SYNOPSIS OF HEAVISIDE'S SYSTEM.

A dielectric supports two kinds of disturbance, electric and magnetic. The electric force $\mathbf{E}$ produces, or is associated with, the displacement $\mathbf{D}$, and the magnetic force $\mathbf{H}$ produces the displacement $\mathbf{B}$. Thus,

$$\mathbf{D}=c\mathbf{E} \qquad\qquad \mathbf{B}=\mu\mathbf{H}$$

In an ideal dielectric c and μ are constants, such that $\mu cv^2=1$, if v is the velocity of propagation of disturbances.

Spacial displacement, or a translation a given distance and in a given direction, is the primitive vector, and all quantities derivable from it by differentiation are also vectors. Thus, velocity and acceleration; then force by a scalar multiplication; or electric force and magnetic force in the same way (e. g., $\mathbf{E}\rho$ is the moving force of $\mathbf{E}$ on ρ of electrification), then electric current and so on. The polygon of displacements is obvious; that of all vectors follows. The *activity* of a force $\mathbf{F}$ with velocity $\mathbf{v}$ is $\mathbf{Fv}$, whether they are parallel or not. When parallel, $\mathbf{Fv}$ is the same as Fv. In general $\mathbf{Fv}=Fv\cos(\widehat{\mathbf{Fv}})$. This defines the scalar product of any two vectors. Similarly the activities of $\mathbf{E}$ and $\mathbf{H}$ are $\mathbf{E}\dot{\mathbf{D}}$ and $\mathbf{H}\dot{\mathbf{B}}$. The electric and magnetic *energies stored* are:

$$U=\int\mathbf{E}\dot{\mathbf{D}}dt=\int_0^D\mathbf{E}d\mathbf{D} \qquad\qquad T=\int\mathbf{H}\dot{\mathbf{B}}dt=\int_0^B\mathbf{H}d\mathbf{B}$$

When $\mathbf{D}$ and $\mathbf{B}$ are linearly related to $\mathbf{E}$ and $\mathbf{H}$

$$U=\tfrac{1}{2}\mathbf{ED}=\tfrac{1}{2}\mathbf{E}c\mathbf{E} \qquad\qquad T=\tfrac{1}{2}\mathbf{HB}=\tfrac{1}{2}\mathbf{H}\mu\mathbf{H}$$

Here c and μ need not be scalar constants, but the linear operators turning $\mathbf{E}$ to $\mathbf{D}$ or $\mathbf{H}$ to $\mathbf{B}$. If they are constants, as in the ether,

$$U=\tfrac{1}{2}cE^2 \qquad\qquad T=\tfrac{1}{2}\mu H^2$$

In material bodies these equations may also be approximately true, with changed values of c and μ, caused by matter. In most bodies μ is a trifle greater or a trifle less than in ether, but in some bodies (magnetic) largely greater. Then the linear relation is not true for small forces. $\mathbf{B}$ does not depend on $\mathbf{H}$ alone on account of hysteresis. On the other hand, c is always increased little or much, but not enormously, like μ in iron. The linear relation also loses full validity. It is in crystalline media that c and μ become linear operators. Then $\mathbf{D}=c\mathbf{E}$ means $D_1=c_1E_1$, $D_2=c_2E_2$, $D_3=c_3E_3$, if $D_1D_2D_3$, are the components of D and $E_1E_2E_3$, those of E in the three mutually $\perp$ directions, in which D or E are parallel, whilst $c_1c_2c_3$ are the principal permittivities. Similarly with μ. If μ_0, c_0 are the etherial constants, then $\frac{\mu}{\mu_0}$, $\frac{c}{c_0}$ are the specific inductivity and specific permittivity, mere numerics, like specific gravity, equal to the ratio of weight or mass of one body to that of a standard body of the same bulk.

Besides storing energy, bodies can not support electric force without wasting energy. In an electric dielectric

$$Q_1=\mathbf{EC}=\mathbf{E}k\mathbf{E} \quad \text{(rate of waste)}$$

$$\mathbf{C}=\ k\mathbf{E} \quad \text{(Ohm's Law, for the unit volume).}$$

If k is the conductivity, $\mathbf{C}$ the conduction current, k may be a linear operator, but if only a scalar constant, so that $\mathbf{E}\parallel\mathbf{C}$ (parallel to), then $Q_1=EC=kE^2$.

The reciprocal of k is the resistivity. The total activity of $\mathbf{E}$ is now

$$\mathbf{E}(\mathbf{C}+\dot{\mathbf{D}})=Q_1+\dot{U}$$

Similarly, in a magnetic conductor (if it existed) we should have

$$\mathbf{H}(\mathbf{G}+\dot{\mathbf{B}})=Q_2+\dot{T},$$

where $\mathbf{G}$ is the magnetic conduction current, and $Q_2=\mathbf{HG}$, $\mathbf{G}=g\mathbf{H}$, so that g is the magnetic conductivity (fictitious).

$\mathbf{C}+\dot{\mathbf{D}}$ is the true electric current in MAXWELL's sense, and $\mathbf{G}+\dot{\mathbf{B}}$ would be the true magnetic current. But in reality it is only $\dot{\mathbf{B}}$. These true currents have to be supplemented later.

The line integral of the effective electric force along any path is the *voltage* or E. M. F.; the line integral of the magnetic force along any path is the *gaussage* or M. M. F.

Everything relating to $\mathbf{E}$ and $\mathbf{H}$ concerns the unit cube, its volume, side, edge. When we pass to voltage and gaussage we require to consider the total fluxes through areas, and total wastes in volumes, in their relation to voltage and gaussage. Thus,

$\mathbf{C}=k\mathbf{E}$ becomes $C=KV$ or $V=RC$
$\mathbf{D}=c\mathbf{E}$ becomes $Q=SV$
$\mathbf{B}=\mu\mathbf{H}$ becomes $P=LC$

It is convenient to distinguish between the *density* of a *flux* and the *intensity* of a *force*.

K is the conductance (electric) of a wire, for example.
R is the resistance (electric) of a wire, for example.
S is the permittance of a condenser.
S^{-1} is the elastance of a condenser.
L is the inductance of a magnetic circuit or portion thereof.
L^{-1} is the reluctance of a magnetic circuit or portion thereof.
Q is the charge of the condenser.
P is the momentum of the current C, line integral of effective $\mathbf{H}$ embracing C.
The energy of condenser is $\frac{1}{2}SV^2=\frac{1}{2}VQ$.
The energy of current is $\frac{1}{2}LC^2=\frac{1}{2}CP$.
The activity of the voltage is, when condenser is also conducting:

$$V(C+\dot{Q})=RC^2+\frac{d}{dt}(\tfrac{1}{2}SV^2)$$

In the core of the coils it is convenient as regards the external connections to make the current in any turn be C instead of the total current in all.

Thus, $P=(L_1N)C$ is the flux of induction through any turn; L_1 signifies now the permeance and the energy is $\frac{1}{2}P(NC)=\frac{1}{2}(L_1N^2)C^2=\frac{1}{2}LC^2$. This L is the inductance. If there is only one turn of wire, then it and the permeance are the same. It is N^2 times the permeance of the turns.

CROSS CONNECTIONS OF ELECTRIC AND MAGNETIC PHENOMENA.

First circuital law.—The positive circuitation of the magnetic force measures the electric current.

Second circuital law.—The negative circuitation of the electric force measures the magnetic current.

These apply to any circuit (closed line) irrespective of material. The circuitation is once along and around the circuit. The current is the total through the closed line. Thus, the circuital gaussage measures the electric current, and the negative of the circuital voltage measures the magnetic current.

Passing to unit volume the fluxes are $\mathbf{J}$ $\mathbf{G}$ (true currents).

$$\left.\begin{array}{lr}\text{The first circuital law is} & \operatorname{curl}\mathbf{H}_1=\mathbf{J}\\ \text{“ second “ “ “} & -\operatorname{curl}\mathbf{E}_1=\mathbf{G}\end{array}\right\}\text{ in a stationary medium, unelectrified.}$$

Take unit area ⊥ to $\mathbf{J}$ and $\mathbf{G}$ in order to identify with the more general forms above of the circuital laws. Curl is therefore the circuitation per unit area ⊥ to the flux.

$\mathbf{H}_1$ and $\mathbf{E}_1$ are the forces of the field, not counting impressed or intrinsic forces.

Equation of activity $\mathbf{EJ}+\mathbf{HG}=Q+\dot{U}+\dot{T}$ when there are no impressed forces.

Total in all space $0=\Sigma(Q+\dot{U}+\dot{T})=Q_0+\dot{U}_0+\dot{T}_0$.

If the impressed forces are **f** and the velocities are **v** then

$$\Sigma \mathbf{fv} = Q_o + \dot{U}_o + \dot{T}_o .$$

If impressed forces are of electricity and magnetism, type **e** and **h**, then

$$\Sigma\,(\mathbf{eJ} + \mathbf{hG}) = Q_o + \dot{U}_o + \dot{T}_o$$

only true in total since fluxes of energy are not considered.

If **H** and **E** are forces of the fluxes **D** and **B** and if also intrinsic or impressed forces **h** and **e** exist, then

$$\mathbf{H} = \mathbf{H}_1 + \mathbf{h} \qquad \mathbf{E} = \mathbf{E}_1 + \mathbf{e}$$

It is $\mathbf{H}_1$ and $\mathbf{E}_1$ that occur in circuital laws or

$$\operatorname{curl}\,(\mathbf{H} - \mathbf{h}) = \mathbf{J}.$$

$$-\operatorname{curl}\,(\mathbf{E} - \mathbf{e}) = \mathbf{G}.$$

e may include voltaic force, thermoelectric force, force of intrinsic electrification, impressed electric force, etc.

h may include force of intrinsic magnetization, impressed magnetic force, etc.

Intrinsic electrification is the function of displacement, temporary or permanent, $\mathbf{I}_1 = c\mathbf{e}$:

Intrinsic magnetization is the function of induction, temporary or permanent, $\mathbf{I}_2 = \mu\mathbf{h}$.

The mechanical product $V\mathbf{ab}$ of **a** and **b** is a vector of the size **ab** sin $\mathbf{a}$^$\mathbf{b}$ $\perp$ to both **a** and **b**, with the right-handed screw relation between +translation and +rotation.

Thus, if **a** is to the north and **b** to the east, then $V\mathbf{ab}$ is downward; $V\mathbf{ab} = -V\mathbf{ba}$.

The mechanical electric force is $\mathbf{e} = V\mathbf{qB}$, the mechanical magnetic force is $\mathbf{h} = V\mathbf{Dq}$, when **q** is the velocity of the medium. It is a quasi-impressed force introduced to let the circuital laws be true for a moving medium.

$$\text{Thus} \qquad \begin{array}{r} \operatorname{curl}\,(\mathbf{H} - V\mathbf{Dq}) = \mathbf{J} \\ -\operatorname{curl}\,(\mathbf{E} - V\mathbf{qB}) = \mathbf{G} \end{array} \quad \left\{ \begin{array}{l} \text{unelectrified moving medium and} \\ \text{no intrinsic forces.} \end{array} \right\}$$

Express the same circuital laws when the medium is moving; **q** the velocity at any point.

Electromagnetic force is $V\mathbf{JB}$. (Moving force, unit volume.)
Magnetoelectric force is $V\mathbf{DG}$.

$$\begin{array}{lrcl} \text{Their activities are} & \mathbf{q}\,V\mathbf{JB} & \text{and} & \mathbf{q}\,V\mathbf{DG} \\ \text{or} & \mathbf{J}\,V\mathbf{Bq} & \text{and} & \mathbf{G}\,V\mathbf{qD} \\ \text{or} & -\mathbf{eJ} & \text{and} & -\mathbf{hG} \end{array}$$

Looking from the other side, the negatives of $V\mathbf{JB}$ and $V\mathbf{DG}$ are the impressed mechanical forces; so $\mathbf{e} = V\mathbf{qB}$ and $\mathbf{h} = V\mathbf{Dq}$ are the equivalent impressed electric and magnetic forces.

General.—The divergence of any flux is the amount leaving the unit volume.

Special.—The divergence of the displacement is the density of the electrification.

$$\begin{array}{ll} \text{Electrification} & \rho = \operatorname{div} D \\ \text{Magnetification} & \sigma = \operatorname{div} B \ \text{(fictitious)} \end{array}$$

or electrification is the source of displacement, when not circuital,

$$D = \frac{\rho}{4\pi r^2} \qquad B = \frac{\sigma}{4\pi r^2}$$

are the densities of D and B at distance r, due to ρ or σ, when spreading isotropically from the point.

When electrification moves it makes an electric current. The true currents, then, are

$$\mathbf{J}=\mathbf{C}+\dot{\mathbf{D}}+\rho\mathbf{u}$$

$$\mathbf{G}=\mathbf{K}+\dot{\mathbf{B}}+\sigma\mathbf{w}$$

when there is ρ and σ moving at the place. Use these in the circuital laws, omitting, however the q terms if medium is at rest. **quw** may be all different, at least.

HEAVISIDE'S VECTORIAL ANALYSIS.

Scalars are in roman type, P (x . y . z.)

Vectors are in black letters, **D** . **e**.

Scalar product, $\mathbf{ab}=ab\cos\widehat{\mathbf{ab}}$.

Vector product, $V\mathbf{ab}=ab\sin\widehat{\mathbf{ab}}$, and ⊥ to **a** and **b**.

The tensor or size of a vector **A** is A; components A_1, A_2, A_3

Vector differentiator, $\nabla=\mathbf{i}\frac{d}{dx}+\mathbf{j}\frac{d}{dy}+\mathbf{k}\frac{d}{dz}$; $\nabla_1=\frac{d}{dx}$; $\nabla_2=\frac{d}{dy}$; $\nabla_3=\frac{d}{dz}$.

The *slope* of a scalar P in its space variation:

$$\nabla P=\mathbf{i}\frac{dP}{dx}+\mathbf{j}\frac{dP}{dy}+\mathbf{k}\frac{dP}{dz}=\text{a vector}.$$

Usually $-\triangle$ the slope downwards is considered.

The *divergence* of a vector **D** is the scalar product:

$$\nabla\mathbf{D}=\text{div }\mathbf{D}=\frac{dD_1}{dx}+\frac{dD_2}{dy}+\frac{dD_3}{dz}.$$

The *curl* of a vector **E** is the vector product:

$$V\nabla\mathbf{E}=\mathbf{i}\left(\frac{dE_3}{dy}-\frac{dE_2}{dz}\right)+\mathbf{j}\left(\frac{dE_1}{dz}-\frac{dE_3}{dx}\right)+\mathbf{k}\left(\frac{dE_2}{dx}-\frac{dE_1}{dy}\right).$$

Physical examples.

Scalars.—Density, pressure, temperature, potential, etc.

Vectors.—Displacement, velocity, force, electric current, etc.

The divergence of any flux **D** is the strength of D.

The curl of magnetic force is electric current.

Any physical magnitude is a vector that can be derived from the fundamental vector spacial distribution by differentiation—e. g., velocity and acceleration; then force by multiplying by a scalar; then electric and magnetic force in the same way; then electric current, etc.

The polygon of displacements is obvious, and the same follows for all vectors.

Common system: 4π lines of force emanate from the unit pole.

Heaviside's system: One line of force emanates from the unit pole.

TABLE 29.—*Electricity*.

FUNDAMENTAL RELATIONS.

(Omit the factor (4π) in order to transpose from common to Heaviside's units.)

1.	c	*Permittivity.* or Spec. Ind. Capac.	$\frac{1}{(4\pi)}c\mathbf{E}=\mathbf{D}$	S	*Permittance.*	$Q=SV$ Charge.
2.	$\frac{1}{c}$	Elastivity.	$\frac{1}{c}(4\pi)\mathbf{D}=\mathbf{E}$	$\frac{1}{S}$	Elastance.	$V=\frac{Q}{S}$
3.	k	*Conductivity.*	$\mathbf{C}=k\mathbf{E}$	K	*Conductance.*	$C=KV$
4.	$\frac{1}{k}$	Resistivity.	$\frac{1}{k}\mathbf{C}=\mathbf{E}$	R	Resistance.	$V=RC=\frac{1}{K}C$
5.	$\frac{c}{c_o}$	Specific permittivity or dielectric constant.		P	Momentum.	$P=LC$

6.	ρ	Electrification or volume density=charge		$\rho=\text{div }\mathbf{D}$; Also $\rho=\frac{R}{2L}+\frac{K}{2S}$
7.	$\mathbf{e}_o$	Intrinsic electric force (voltaic, thermoelectric)		$\mathbf{e}_o=\frac{1}{c}\mathbf{I}_1$
8.	$\mathbf{e}$	Motional electric force.		$\mathbf{e}=V\mathbf{qB}$
9.	$\mathbf{E}$	Electric force of flux	$\mathbf{E}\ (\mathbf{X}\,.\,\mathbf{Y}\,.\,\mathbf{Z})$	$\mathbf{E}=\mathbf{E}_1+\mathbf{e}$
10.	$\mathbf{E}_1$	Electric force of field.		$\mathbf{E}_1=(\mathbf{E}-\mathbf{e}_o-\mathbf{e})$
11.	$\mathbf{D}$	Displacement	$\mathbf{D}\ (\mathbf{f}\,.\,\mathbf{g}\,.\,\mathbf{h})$	$\mathbf{D}=\frac{c\mathbf{E}}{(4\pi)}=SV=Q$ for a condenser.
12.	(V)	Line integral of electric force=voltage.		$(V)=\frac{1}{S}D$
13.	$\mathbf{C}$	Conduction current	$\mathbf{C}\ (\mathbf{u}\,.\,\mathbf{v}\,.\,\mathbf{w})$	$\mathbf{C}=k\mathbf{E}.$
14.	$\mathbf{D}$	Displacement current	$\dot{\mathbf{D}}\left(\frac{\partial f}{\partial t}\cdot\frac{\partial g}{\partial t}\cdot\frac{\partial h}{\partial t}\right)$	
15.	$\rho\mathbf{u}$	Convection current	$\rho\ (\dot{x}\,.\,\dot{y}\,.\,\dot{z})$	
16.	$\mathbf{j}$	Electric current due to motion of medium.		$(4\pi)\mathbf{j}=\text{curl }\mathbf{h}=\text{curl }V\mathbf{Dq}$
17.	Γ_1	Maxwell's electric current	$\Gamma_1(\mathbf{p}\,.\,\mathbf{q}\,.\,\mathbf{r})$	$\Gamma_1=\mathbf{C}+\dot{\mathbf{D}}=k\mathbf{E}+\frac{c\dot{\mathbf{E}}}{(4\pi)}=\text{curl }\mathbf{H}\frac{1}{(4\pi)}$
18.	$\mathbf{J}$	True electric current.		$\mathbf{J}=\mathbf{C}+\dot{\mathbf{D}}+\rho\mathbf{u}=\text{curl }\mathbf{H}_1\frac{1}{(4\pi)}$
19.	$\mathbf{J}_o$	Total electric current in moving medium.		$\mathbf{J}_o=\mathbf{C}+\dot{D}+\rho\mathbf{u}+\mathbf{j}$
20.	Q_1	Joulean waste, as in a wire.		$Q_1=k\mathbf{E}^2=\mathbf{CE}.$
21.	U	Electric energy stored.	$U=\int_o^D\mathbf{E}d\mathbf{D}$ generally;	$U=\frac{1}{2}\mathbf{ED}=\frac{1}{2}\frac{c\mathbf{E}^2}{(4\pi)}$
22.	P	Potential.		
23.	$\mathbf{F}$	Mechanical force.	$\mathbf{fq}=$work.	$\mathbf{F}=V\mathbf{CB}$
24.	$\mathbf{I}_1$	Intrinsic electrization.		$\mathbf{I}_1=c\mathbf{e}\frac{1}{(4\pi)}$
25.	$\mathbf{W}$	Flux of energy.		$(4\pi)\mathbf{W}=V(\mathbf{E}-\mathbf{e}_o)(\mathbf{H}-\mathbf{h}_o)=V\mathbf{E}_1\mathbf{H}$
26.	ψ	Current function.		
27.	Ψ	Potential of free electricity.		
28.	φ	Velocity potential.		
29.	A	Vector potential.	$\mathbf{A}\ (\mathbf{F}.\ \mathbf{G}.\ \mathbf{H}.)$	$\mathbf{A}=\mathbf{EJ}+\mathbf{HG}=Q+\dot{U}+\dot{T}$

TABLE 30.—*Magnetism.*

FUNDAMENTAL RELATIONS.

(Omit the factor (4π) in order to transpose from common to Heaviside's units.)

30.	μ	*Inductivity.*	$\mathbf{B}=\mu\mathbf{H}=[1+(4\pi)\kappa]\,\mathbf{H}$	L *Inductance*	$P=LC$
				L_1 Permeance	$P=(L_1N)C$
31.	κ	Susceptibility.	$\mathbf{I}=\kappa\mathbf{H}$	$\frac{1}{L}$ Reluctance	$C=\frac{1}{L}P$
32.	g	Magnetic conductivity.	$\mathbf{K}=g\mathbf{H}$	(R) Magnetic conductance	$K=(R)G$
33.	$\frac{1}{g}$	Magnetic resistivity.	$\frac{1}{g}\mathbf{K}=\mathbf{H}$	K Leakage conductance.	
34.	$\frac{\mu}{\mu_o}$	Specific inductivity or permeability.	$\frac{\mu}{\mu_o}=1+(4\pi)\kappa$		
35.	σ	Magnetification. (nonexistent)		$\sigma=\text{div}\,\mathbf{B}$	Also $\sigma=\frac{R}{2L}-\frac{K}{2S}$
36.	$\mathbf{h}_o$	Intrinsic magnetic force (intrinsic magnetization of magnets).		$\mathbf{h}_o=\frac{1}{\mu}\mathbf{I}_2$	
37.	$\mathbf{h}$	Motional magnetic force as induced.		$\mathbf{h}=V\mathbf{Dq}\times(4\pi)$	
38.	$\mathbf{H}$	Magnetic force of flux	$\mathbf{H}\,(\alpha\,.\,\beta\,.\,\gamma)$	$\mathbf{H}=\mathbf{h}+\mathbf{H}_1$	
39.	$\mathbf{H}_1$	Magnetic force of field.		$\mathbf{H}_1=\mathbf{H}-\mathbf{h}_o-\mathbf{h}$	
40.	$\mathbf{B}$	Magnetic induction	$\mathbf{B}\,(\mathbf{a}\,.\,\mathbf{b}\,.\,\mathbf{c})$	$\mathbf{B}=\mu\mathbf{H}$	
41.	(G)	Line integral of magnetic force=Gaussage.		$\mathbf{G}=-\text{curl}\,\mathbf{E}_1$	
42.	$[\mathbf{K}]$	Magnetic conduction current (fictitious).		$[\mathbf{K}]=g\mathbf{H}$	
43.	$\sigma\mathbf{w}$	Convection current.	$\sigma\,(\dot{x}\,.\,\dot{y}\,.\,\dot{z})$		
44.	$\mathbf{g}$	Magnetic current due to motion.		$\mathbf{g}=-\text{curl}\,\mathbf{e}\,\frac{1}{(4\pi)}$	
45.	Γ_2	(Maxwell's) magnetic current.		$\Gamma_2=[\mathbf{K}]+\frac{1}{(4\pi)}\dot{\mathbf{B}}=-\frac{\text{curl}\,\mathbf{E}}{(4\pi)}$	
46.	$\mathbf{G}$	True magnetic current.		$\mathbf{G}=[\mathbf{K}]+\frac{1}{(4\pi)}\dot{\mathbf{B}}+[\sigma\mathbf{w}]=-\frac{\text{curl}\,\mathbf{E}_1}{(4\pi)}$	
47.	$\mathbf{G}_o$	Total magnetic current in moving medium.		$\mathbf{G}_o=[\mathbf{K}]+\frac{1}{(4\pi)}\dot{\mathbf{B}}+[\sigma\mathbf{w}]+\mathbf{g}$	
48.	Q_2	Joulean waste (fictitious).		$Q_2=g\mathbf{H}^2=\mathbf{KH}$	
49.	T	Magnetic energy stored.	$T=\int_o^{\mathbf{B}}\mathbf{H}\,\frac{d\mathbf{B}}{(4\pi)}$ generally;	$T=\frac{1}{2}\frac{\mathbf{HB}}{(4\pi)}=\frac{1}{2}\frac{\mu\mathbf{H}^2}{(4\pi)}$	
50.	$\mathbf{A}$	Vector potential or momentum	$\mathbf{A}\,(\mathbf{F}\,.\,\mathbf{G}\,.\,\mathbf{H})$	$\mathbf{A}=\mathbf{EJ}+\mathbf{HG}=Q+\dot{\Gamma}+\dot{T}$	
51.	$\mathbf{I}_2$	Intrinsic magnetization	$\mathbf{I}_2\,(\mathbf{A}\,.\,\mathbf{B}\,.\,\mathbf{C})$	$\mathbf{I}_2=-\nabla\Omega=\mu\mathbf{h}\frac{1}{(4\pi)}=\kappa\mathbf{F}$	
52.	Ω	Magnetic potential.			

TABLE 31.—*J. J. Thomson's electromagnetic system and notation.*

[Recent Researches; Phil. Mag., July, 1889; Elements.]

(In common units.)

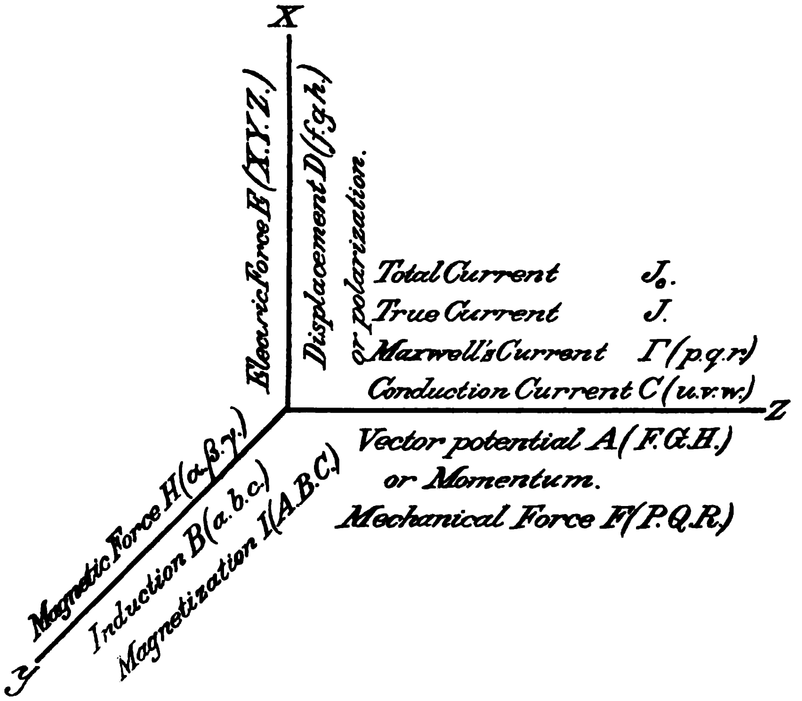

CHART 33.—Relative axial relations of the electric and magnetic quantities.

f_x= the number of electrostatic lines at the point xyz through the unit area at right angles to x; f_y to y; f_z to z.

This may be changed in three ways:

1. By bringing new lines into the area.
2. By spreading or contracting the lines through their relative motion.
3. By changing the direction of the lines through rotation.

These give the strength, divergence, and rotation of the field.

53. 1. $\delta_1 f_x = -\delta t\left(u\frac{\partial f}{\partial x}+v\frac{\partial f}{\partial y}+w\frac{\partial f}{\partial z}\right)\cdot$ Number of new lines added.

2. $\delta_2 f_x = -\delta t f\left(\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\cdot$ Number added through convergence.

3. $\delta_3 f_x = \quad \delta t\ \left(g\frac{\partial u}{\partial y}+h\frac{\partial u}{\partial z}\right)\cdot$ Number added by deflection of direction.

54. Total variation. $\delta f_x = \delta_1 f + \delta_2 f + \delta_3 f = \left[-\left(u\frac{\partial f}{\partial x}+v\frac{\partial f}{\partial y}+w\frac{\partial f}{\partial z}\right)-f\left(\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)+\left(g\frac{\partial u}{\partial y}+h\frac{\partial u}{\partial z}\right)\right]\delta t.$

55. $\frac{df_x}{dt} = \frac{\partial}{\partial y}(ug-vf)-\frac{\partial}{\partial z}(wf-uh)-u\left(\frac{\partial f}{\partial x}+\frac{\partial g}{\partial y}+\frac{\partial h}{\partial z}\right)\cdot$

56. Density. ρ=density of free electricity$=\frac{\partial f}{\partial x}+\frac{\partial g}{\partial y}+\frac{\partial h}{\partial z}\cdot$

57. Maxwell's current.

$$\Gamma_1=\begin{cases} p=\dfrac{\partial f}{\partial t}+u\rho=\dfrac{\partial}{\partial y}(ug-vf)-\dfrac{\partial}{\partial z}(wf-uh). \\ q=\dfrac{\partial g}{\partial t}+v\rho=\dfrac{\partial}{\partial z}(vh-wg)-\dfrac{\partial}{\partial x}(ug-vf). \\ r=\dfrac{\partial h}{\partial t}+w\rho=\dfrac{\partial}{\partial x}(wf-uh)-\dfrac{\partial}{\partial y}(vh-wg). \end{cases}$$

Rate of variation of the electric field through displacement and convection currents.

58. First circuital law.

$$4\pi J=\begin{cases} 4\pi p=\dfrac{\partial\gamma}{\partial y}-\dfrac{\partial\beta}{\partial z}. \\ 4\pi q=\dfrac{\partial\alpha}{\partial z}-\dfrac{\partial\gamma}{\partial x}. \\ 4\pi r=\dfrac{\partial\beta}{\partial x}-\dfrac{\partial\alpha}{\partial y}. \end{cases}$$

The positive magnetic circuitation measures the electric current through the circuit.

59. Second circuital law.

$$4\pi G=\begin{cases} -\dfrac{\partial a}{\partial t}=\dfrac{\partial Z}{\partial y}-\dfrac{\partial Y}{\partial z}. \\ -\dfrac{\partial b}{\partial t}=\dfrac{\partial X}{\partial z}-\dfrac{\partial Z}{\partial x}. \\ -\dfrac{\partial c}{\partial t}=\dfrac{\partial Y}{\partial x}-\dfrac{\partial X}{\partial y}. \end{cases}$$

The negative electric circuitation measures the magnetic current through the circuit.

The motion of an electrostatic line gives rise to a magnetic force at right angles to itself and to the direction of motion. $h=VDq$.

60. Magnetic force.

$$H=\begin{cases} \alpha=4\pi(vh-wg). \\ \beta=4\pi(wf-uh). \\ \gamma=4\pi(ug-uf). \end{cases}$$

The vector product is referred to the right-handed rotation and translation for the axes $x.y.z.$

Let $c=$ the specific inductive capacity for electricity in the medium.
$\mu=$ the specific inductive capacity for magnetism in the medium.
$k=$ the coefficient of conductivity in matter for electricity.
$\kappa=$ the coefficient of induced magnetization. $\mu=1+4\pi\kappa$.

Electric force is due to the motion of electrostatic lines in a medium whose specific inductive capacities are c μ.

61. Electric induction or electromotive force.

$$E=\begin{cases} X=\dfrac{4\pi}{c}f=\mu(w\beta-v\gamma)=wb-vc=\dfrac{dT}{df}. \\ Y=\dfrac{4\pi}{c}g=\mu(u\gamma-w\alpha)=uc-wa=\dfrac{dT}{dg}. \\ Z=\dfrac{4\pi}{c}h=\mu(v\alpha-u\beta)=va-ub=\dfrac{dT}{dh}. \end{cases}$$

62. Magnetic induction.

$$B=\begin{cases} a=\mu\alpha=(1+4\pi\kappa)\alpha=\alpha+4\pi A. \\ b=\mu\beta=(1+4\pi\kappa)\beta=\beta+4\pi B. \\ c=\mu\gamma=(1+4\pi\kappa)\gamma=\gamma+4\pi C. \end{cases}$$

63.

$$B=\begin{cases} a=4\pi\mu(vh-wg)=\dfrac{\partial H}{\partial y}-\dfrac{\partial G}{\partial z}. \\ b=4\pi\mu(wf-uh)=\dfrac{\partial F}{\partial z}-\dfrac{\partial H}{\partial x}. \\ c=4\pi\mu(ug-vf)=\dfrac{\partial G}{\partial x}-\dfrac{\partial F}{\partial y}. \end{cases}$$

64. Magnetization. $I=\begin{cases} A=\kappa\alpha=4\pi\kappa(vh-wg). \\ B=\kappa\beta=4\pi\kappa(wf-uh). \\ C=\kappa\gamma=4\pi\kappa(ug-vf). \end{cases}$

65. Velocity of transmission. $v^2=\dot{x}^2+\dot{y}^2+\dot{z}^2=\frac{1}{\mu c}$ $\mu c v^2=1.$

The motion of the electrostatic lines involves kinetic energy T.

66. Kinetic energy. $T=\frac{\mu}{8\pi}(\alpha^2+\beta^2+\gamma^2).$

$$=2\pi\mu\left[(hu-gw)^2+(fw-hu)^2+(gu-fv)^2\right].$$

67. Momentum per unit volume or vector potential.

$$A=\begin{cases} F=\frac{dT}{du}=4\pi\mu\left[g(gu-fv)-h(fw-hu)\right]=gc-hb. \\ G=\frac{dT}{dv}=4\pi\mu\left[h(hv-gw)-f(gu-fv)\right]=ha-fc. \\ H=\frac{dT}{dw}=4\pi\mu\left[f(fw-hu)-g(hv-gw\right]=fb-ga. \end{cases}$$

Direction cosines of the inwardly directed normal to the surface dS.

68. Number of lines of electrostatic force.

$$J=\begin{cases} p=c\Sigma g-b\Sigma h=\int\int\Sigma f(lu+mv+nw). \\ q=a\Sigma h-c\Sigma f=\int\int\Sigma g(lu+mv+nw). \\ r=b\Sigma f-a\Sigma g=\int\int\Sigma h(lu+mv+nw). \end{cases}$$

69. Mechanical force. $F=\begin{cases} P=cq-br. \\ Q=ar-cp. \\ R=bp-aq. \end{cases}$ This is the force tending to move a conductor which carries a current in a magnetic field.

70. Let ψ=current function=distribution of density over a surface.
Ψ=potential of free electricity.

71. Electrical potential. $P=\int\int\frac{\psi}{r}dS.$ P_0=external field; P=outside, P'=inside the surface.

72. Magnetic potential. $\Omega=\int\int\frac{d}{dr}\cdot\frac{\psi}{r}dS.$ $=-\frac{1}{a}\frac{d}{dr}(Pr)$ on a sphere.

73. Vector potential. $F=n\frac{dP}{dy}-m\frac{dP}{dz}\cdot$ $G=l\frac{dP}{dz}-n\frac{dP}{dx}\cdot$ $H=m\frac{dP}{dx}-l\frac{dP}{dy}\cdot$

74. Magnetic induction. $\mu\alpha=\frac{dH}{dy}-\frac{dG}{dz}=-\frac{d\Omega}{dx}\cdot$ $\mu\beta=\frac{dF}{dz}-\frac{dH}{dx}=-\frac{d\Omega}{dy}\cdot$ $\mu\gamma=\frac{dG}{dx}-\frac{dF}{dy}=-\frac{d\Omega}{dz}.$

75. Electric force. $X=-\frac{dF}{dt}-\frac{d\Psi}{dx}=\frac{1}{k}u.$ $Y=-\frac{dG}{dt}-\frac{d\Psi}{dy}=\frac{1}{k}u.$ $Z=-\frac{dH}{dt}-\frac{d\Psi}{dz}=\frac{1}{k}w.$

76. Conduction current. $u=n\frac{d\psi}{dy}-m\frac{d\psi}{dz}\cdot$ $v=l\frac{d\psi}{dz}-n\frac{d\psi}{dx}\cdot$ $w=m\frac{d\psi}{dx}-l\frac{d\psi}{dy}\cdot$

77. Maxwell's electric current. $\begin{cases} p_1=k\frac{4\pi}{c}f=kX=u. \\ p_2=\frac{df}{dt}. \end{cases}$ $\begin{cases} q_1=k\frac{4\pi}{c}g=kY=v. \\ q_2=\frac{dg}{dt}. \end{cases}$ $\begin{cases} r_1=k\frac{4\pi}{c}h=kZ=w. \\ r_2=\frac{dh}{dt}. \end{cases}$

TABLE 32.—*Connections between electricity and magnetism.*

[In Heaviside's units.]

CIRCUITATION.

78. I. First circuital law: The *positive* magnetic circuitation measures the electric current through the circuit.

79. II. Second circuital law: The *negative* electric circuitation measures the magnetic current through the circuit.

80. I. $\text{curl}\,\mathbf{H}_1 = \text{curl}\,(\mathbf{H}-\mathbf{h}_o-\mathbf{h}) = (4\pi)\,\mathbf{J} = (4\pi)\left(\mathbf{C}+\frac{1}{(4\pi)}\dot{\mathbf{D}}+\rho\mathbf{u}\right).$

or $\text{curl}\,(\mathbf{H}-\mathbf{h}_o) = (4\pi)\,\mathbf{J}_o = (4\pi)\left(\mathbf{C}+\frac{1}{(4\pi)}\dot{\mathbf{D}}+\rho\mathbf{u}+\mathbf{j}\right).$

81. II. $-\text{curl}\,\mathbf{E}_1 = -\text{curl}\,(\mathbf{E}-\mathbf{e}_o-\mathbf{e}) = (4\pi)\mathbf{G} = (4\pi)\left(\mathbf{K}+\frac{1}{(4\pi)}\dot{\mathbf{B}}+\sigma\mathbf{w}\right).$

or $-\text{curl}\,(\mathbf{E}-\mathbf{e}_o) = (4\pi)\mathbf{G}_o = (4\pi)\left(\mathbf{K}+\frac{1}{(4\pi)}\dot{\mathbf{B}}+\sigma\mathbf{w}+\mathbf{g}\right).$

82. Electric energy of medium. $U=\frac{1}{2}\mathbf{ED}=\frac{1}{2}\frac{c\mathbf{E}^2}{(4\pi)}=\frac{1}{2}\frac{\mathbf{E}c\mathbf{E}}{(4\pi)}$ $\frac{1}{2}DV=\frac{1}{2}SV^2$. Condenser.

83. Magnetic energy of medium. $T=\frac{1}{2}\frac{\mathbf{HB}}{(4\pi)}=\frac{1}{2}\frac{\mu\mathbf{H}^2}{(4\pi)}=\frac{\mathbf{H}\mu\mathbf{H}}{(4\pi)}$ $\frac{1}{2}PC=\frac{1}{2}LC^2$. Current in a circuit.

84. Activity. $Q_1+\dot{U}=\mathbf{EC}+\mathbf{E}\dot{\mathbf{D}}$ $Q_2+\dot{T}=\mathbf{HK}+\mathbf{H}\dot{\mathbf{B}}.$

$\Sigma(Q_1+Q_2+\dot{U}+\dot{T})=\Sigma(\mathbf{EJ}+\mathbf{HG})=\Sigma[\mathbf{fq}+\text{conv}\,(\mathbf{A}+\mathbf{q}\,(U+T))].$

85. Flux of energy. Stress flux. $\mathbf{A}=-\left[V\mathbf{eH}+V\mathbf{Eh}+\mathbf{q}(U+T)\right].$

86. Poynting flux. $\mathbf{W}=V(\mathbf{E}-\mathbf{e}_o)(\mathbf{H}-\mathbf{h}_o)\frac{1}{(4\pi)}.$

$\mathbf{W}=V\mathbf{EH}\frac{1}{(4\pi)}$ when there are no intrinsic forces.

$\mathbf{W}=\mathbf{q}(U+T)$ in plane waves and solar radiation.

87. Convective flux. $\mathbf{F}_q=Q_o+U_o+T_o+\text{div}\,q(U_o+T_o).$

88. Medium at rest. $\mathbf{e}_o\mathbf{J}+\mathbf{h}_o\mathbf{G}=Q+\dot{U}+\dot{T}+\text{div}\,\mathbf{W}.$

89. Medium in motion. $\mathbf{e}_o\mathbf{J}_o+\mathbf{h}_o\mathbf{G}_o=Q+\dot{U}+\dot{T}+\mathbf{Fq}+Sa+\text{div}\left[\mathbf{W}+\mathbf{A}+\mathbf{q}(U+T)\right].$

90. Mechanical moving forces. Electric. $\mathbf{F}_e=\mathbf{E}\rho-\frac{1}{2}\mathbf{E}^2\nabla c+[V\mathbf{DG}_o]+V\mathbf{Dg}_o.$

91. Magnetic. $\mathbf{F}_m=[\mathbf{H}\sigma]-\frac{1}{2}\mathbf{H}^2\nabla\mu+V\mathbf{J}_o\mathbf{B}+V\mathbf{j}_o\mathbf{B}.$

92. Complete. $\mathbf{F}=V\dot{\mathbf{D}}\mathbf{B}+V\mathbf{D}\dot{\mathbf{B}}=\frac{d}{dt}V\mathbf{DB}=\frac{1}{v^2}\frac{d\mathbf{W}}{dt}.$ Uncharged condenser.

93. Radiation. $v=$ Velocity. $\mathbf{E}=\mu v\mathbf{H}.$ $V=Lv\mathbf{C}.$ $LSv^2=1.$

$\mathbf{H}=cv\mathbf{E}.$ $C=SvV.$ $\mu cv^2=1.$

94. For distortionless transmission. $\frac{R}{L}=\frac{K}{S}$ or $\frac{g}{\mu}=\frac{k}{c}.$

95. Attenuation factor. For total displacement. $\varepsilon^{-\frac{Kt}{S}}$ or $\varepsilon^{-\frac{Kt}{c}}.$

96. For total induction. $\varepsilon^{-\frac{Rt}{L}}$ or $\varepsilon^{-\frac{gt}{\mu}}.$

97. For head of wave. $\varepsilon^{-\frac{Kt}{2c}}$ or $\varepsilon^{-\frac{Kt}{2S}}$ or $\varepsilon^{-\frac{gt}{2\mu}}$ or $\varepsilon^{-\frac{Rt}{2L}}.$

TABLE 33.—*Equations of motion. Mechanical analogue.*

[In Heaviside's units.]

Coefficients of	Elasticity	Friction	Inertia	Analogue	Notation
98. Translation	$\rho=\rho_o$	$+\ \rho_1\frac{d}{dt}$	$+\ \rho_2\frac{d^2}{dt^2}$	. . . . . mass	Thomson and Tait's notation.
99. Compression	$k=k_o$	$+\ k_1\frac{d}{dt}$	$+\ k_2\frac{d^2}{dt^2}$	Solidity (solid)	$m=k+\frac{1}{3}n$.
100. Distortion	$n=n_o$	$+\ n_1\frac{d}{dt}$	$+\ n_2\frac{d^2}{dt^2}$	Rigidity (jelly)	$n+m=k+\frac{4}{3}n$.
101. Rotation	$\nu=\nu_o$	$+\ \nu_1\frac{d}{dt}$	$+\ \nu_2\frac{d^2}{dt^2}$	. . . . . (ether)	

102. Translation. $\mathbf{f}+\mathbf{F}=\left(\rho_o+\rho_1\frac{d}{dt}+\rho_2\frac{d^2}{dt_2}\right)\mathbf{G}$ $\mathbf{G}$=spacial displacement.

103. Strain. $\mathbf{N}\nabla\mathbf{G}=\mathbf{p}_n-\frac{1}{2}V\mathbf{N}\text{ curl }\mathbf{G}=(\mathbf{p}_n-\frac{1}{3}\mathbf{N}\text{ div }\mathbf{G})+\frac{1}{3}\mathbf{N}\text{ div }\mathbf{G}-\frac{1}{2}V\mathbf{N}\text{ curl }\mathbf{G}$.

104. Equation of motion. $\rho\ddot{\mathbf{G}}=\mathbf{f}+n\nabla^2\mathbf{G}+m\nabla\text{ div }\mathbf{G}$ in ordinary elastic solid.

105. Circuital stress. $\rho\mathbf{G}_1=\mathbf{f}_1+n\nabla^2\mathbf{G}_1$. speed$=\left(\frac{n}{\rho}\right)^{\frac{1}{2}}$.

106. Divergent stress. $\rho\ddot{\mathbf{G}}_2=\mathbf{f}_2+(n+m)\nabla^2\mathbf{G}_2$. speed$=\left(\frac{n+m}{\rho}\right)^{\frac{1}{2}}$.

107. Equilibrium. $\mathbf{f}_1=-n\nabla^2\mathbf{G}_1$. $\mathbf{f}_2=-(n+m)\nabla^2\mathbf{G}_2$.

108. Solid (elastic). $\mathbf{f}_1=\left(\rho\frac{d^2}{dt^2}-n\nabla^2\right)\mathbf{G}$. viscous $\mathbf{f}_1=\left[\rho\frac{d^2}{dt^2}-\left(n_o+n_1\frac{d}{dt}\right)\nabla^2\right]\mathbf{G}$.

109. Liquid. viscous $\mathbf{f}_1=\left[\rho\frac{d^2}{dt^2}-n_1\frac{d}{dt}\nabla^2\right]$

$\mathbf{G}=\rho\frac{d\mathbf{q}}{dt}-n_1\nabla^2\mathbf{q}$.

110. Ether (rotational). $\mathbf{f}_1=\left(\rho\frac{d^2}{dt^2}-\nu\nabla^2\right)\mathbf{G}=\left(\rho\frac{d}{dt}-\nu\int\nabla^2\right)\mathbf{q}=\rho\frac{d}{dt}\mathbf{q}+\text{ curl }(\frac{1}{2}\mathbf{S})$.

	Distortion	Compression	Rotation
111. Strain.	$\mathbf{N}\nabla\mathbf{G}=(\mathbf{p}_n-\frac{1}{3}\mathbf{N}\text{ div }\mathbf{G})$	$+\frac{1}{3}\mathbf{N}\text{ div }\mathbf{G}$	$-\frac{1}{2}V\mathbf{N}\text{ curl }\mathbf{G}$.
112. Stress.	$\mathbf{P}_n=2n(\mathbf{p}_n-\frac{1}{3}\mathbf{N}\text{ div }\mathbf{G})$	$+\mathbf{N}k\text{ div }\mathbf{G}$	$-\nu V\mathbf{N}\text{ curl }\mathbf{G}$.
113. Torque.	$\mathbf{S}=$		$2\nu\text{ curl }\mathbf{G}$.
114. Translational force.	$\mathbf{F}=n(\nabla^2\mathbf{G}+\frac{1}{3}\nabla\text{ div }\mathbf{G})$	$+k\nabla\text{div }\mathbf{G}$	$-\nu\text{ curl}^2\mathbf{G}$.
115. Energy of strain.	$\mathbf{U}=n[(\mathbf{p}_1^2+\mathbf{p}_2^2+\mathbf{p}_3^2-\frac{1}{3}(\text{div }\mathbf{G})^2)]$	$+\frac{1}{2}k(\text{div }\mathbf{G})^2$	$+\frac{1}{2}\nu(\text{curl }\mathbf{G})^2$.

116. Appropriate mechanical analogue of the *rotational ether;* with $E=q=\frac{dG}{dt}$.

$$\begin{array}{lllll}
\mathbf{G}=\int\mathbf{E} & \rho=c & \mathbf{f}_1=\frac{1}{2}\,\mathrm{curl}\,\mathbf{S}_o & \rho\mathbf{q}=\mathbf{D} & \rho_1\mathbf{q}=\mathbf{C}=k\mathbf{E}. \\
\mathbf{q}=\mathbf{E} & \frac{1}{\nu}=\mu & \mathbf{g}_1=-\mathrm{curl}\,\mathbf{q}_o & \frac{1}{2}\rho\mathbf{q}^2=\frac{1}{2}c\mathbf{E}^2 & \frac{1}{2}\rho_o\mathbf{q}^2=\frac{1}{2}\mu\mathbf{H}^2. \\
\quad=\text{a velocity} & & & & \\
 & \rho_1=k & -\frac{1}{2}\mathbf{S}_o=\mathbf{h} & \rho_1\mathbf{q}^2=k\mathbf{E}^2 & V\frac{1}{2}\mathbf{S}\mathbf{q}=V\mathbf{E}\mathbf{H}. \\
 & \left(\rho_1+\rho\frac{d}{dt}\right)\mathbf{q}=\mathbf{C}+\dot{\mathbf{D}} & -\frac{1}{2}\mathbf{S}=\nu\,\mathrm{curl}\,\mathbf{G}=\mathbf{H} & & -\frac{1}{\nu}\frac{1}{2}\,\mathbf{S}=\mathbf{B}=-\mathrm{curl}\,\mathbf{G}.
\end{array}$$

$\mathbf{N}$ is the normal component in all cases.
$\mathbf{f}$ is the impressed force per unit volume.
$\mathbf{p}_n$ is the stress on the plane whose normal is $\mathbf{N}$.
$\mathbf{F}$ is the force arising from stress.
ρ is the density.
$\mathbf{G}$ is the spacial displacement.

TABLE 34.—*Symbolic operations.*

[In Heaviside's units.]

CIRCUITAL TO SURFACE SUMMATIONS (CURL).

From boundary to surface.

117. P=scalar; $\mathbf{H}$=vector; $\mathbf{T}$=unit tangent to curve; $\mathbf{N}$=unit normal to surface.
f=symbol for function.
$\overset{|}{\Sigma}$=line summation or integral around a curve.
$\overset{||}{\Sigma}$=surface summation or integration.
$\overset{|||}{\Sigma}$=volume summation or integration.

118. $\overset{|}{\Sigma}f(\mathbf{T})=\overset{||}{\Sigma}f(VN\nabla)$.

119. Curl theorems:

$$\left\{\begin{array}{llll}
a. & f(\mathbf{T})=\mathbf{T}. & \overset{|}{\Sigma}\mathbf{T} & =0 \quad \text{Closed polygon or any circuit of vectors.} \\
b. & f(\mathbf{T})=\mathbf{T}P. & \overset{|}{\Sigma}\mathbf{T}P & =\overset{||}{\Sigma}V\mathbf{N}\nabla.P \quad =\overset{||}{\Sigma}V\mathbf{N}(\nabla P)=\overset{||}{\Sigma}\mathbf{N}\,\mathrm{curl}\,\mathbf{H}. \\
c. & f(\mathbf{T})=\mathbf{T}\mathbf{H}. & \overset{|}{\Sigma}\mathbf{T}\mathbf{H} & =\overset{||}{\Sigma}(V\mathbf{N}\nabla)\mathbf{H} \quad =\overset{||}{\Sigma}\mathbf{N}\,V\nabla\mathbf{H} \quad =\overset{||}{\Sigma}\mathbf{N}\,\mathrm{curl}\,\mathbf{H}. \\
d. & f(\mathbf{T})=V\mathbf{T}\mathbf{H}. & \overset{|}{\Sigma}V\mathbf{T}\mathbf{H} & =\overset{||}{\Sigma}V(V\mathbf{N}\nabla)\mathbf{H} \quad =\overset{||}{\Sigma}(\nabla\mathbf{H}\mathbf{N}-\mathbf{N}\nabla\mathbf{H}). \\
e. & f(\mathbf{T})=(V\mathbf{T}\mathbf{N})P. & \overset{|}{\Sigma}V\mathbf{T}\mathbf{N}P & =\overset{||}{\Sigma}V(V\mathbf{N}\nabla)\mathbf{N}\,.\,P=\overset{||}{\Sigma}(\nabla P-\mathbf{N}\,.\,\mathbf{N}\nabla P).
\end{array}\right.$$

SURFACE TO VOLUME SUMMATIONS (DIVERGENCE).

From closed surface to inclosed region.

120. P=scalar; $\mathbf{D}$=vector; $\mathbf{N}$=normal from surface; p=a constant or variable.

121. $\overset{||}{\Sigma}f(\mathbf{N})=\overset{|||}{\Sigma}f(\mathbf{D})$.

122. Divergence theorems:

$$
\left\{
\begin{array}{lll}
a. & f(\mathbf{N})=\mathbf{N}. & \overset{\prime\prime}{\Sigma}\mathbf{N}\ =0 \quad \text{Balanced volume.} \\
b. & f(\mathbf{N})=\mathbf{N}p. & \overset{\prime\prime}{\Sigma}\mathbf{N}p\ =0 \qquad\qquad p \text{ constant.} \\
 & & =\overset{\prime\prime\prime}{\Sigma}\nabla p\ =\overset{\prime\prime\prime}{\Sigma}\left(\frac{d\,.\,ip}{dx}+\frac{d\,.\,jp}{dy}+\frac{d\,.\,kp}{dz}\right)p \text{ variable.} \\
c. & f(\mathbf{N})=\mathbf{ND}. & \overset{\prime}{\Sigma}\mathbf{ND}\ =\overset{\prime\prime\prime}{\Sigma}\operatorname{div}D=\overset{\prime\prime\prime}{\Sigma}\left(\frac{dD_1}{dx}+\frac{dD_2}{dy}+\frac{dD_3}{dz}\right). \\
d. & f(\mathbf{N})=\mathbf{ND}P. & \overset{\prime\prime}{\Sigma}\mathbf{ND}P=\overset{\prime\prime\prime}{\Sigma}\nabla(\mathbf{D}P)=\overset{\prime\prime\prime}{\Sigma}\nabla\mathbf{D}P+\overset{\prime\prime\prime}{\Sigma}\mathbf{D}\nabla P. \\
 & & =\overset{\prime\prime\prime}{\Sigma}P\left(\frac{dD_1}{dx}+\frac{dD_2}{dy}+\frac{dD_3}{dz}\right)+\overset{\prime\prime\prime}{\Sigma}\left(D_1\frac{dP}{dx}+D_2\frac{dP}{dy}+D_3\frac{dP}{dz}\right). \\
e. & f(\mathbf{N})=V\mathbf{NH}. & \overset{\prime\prime}{\Sigma}V\mathbf{NH}=\overset{\prime\prime\prime}{\Sigma}\left(\frac{d\,.\,ViH}{dx}+\frac{d\,.\,VjH}{dy}+\frac{d\,.\,VkH}{dz}\right). \\
 & & =\overset{\prime\prime\prime}{\Sigma}V\nabla H. \\
 & & =\overset{\prime\prime\prime}{\Sigma}\operatorname{curl}H. \\
 & & =\overset{\prime\prime\prime}{\Sigma}\left[i\left(\frac{dH_3}{dy}-\frac{dH_2}{dz}\right)+j\left(\frac{dH_1}{dz}-\frac{dH_3}{dx}\right)+k\left(\frac{dH_2}{dx}-\frac{dH_1}{dy}\right)\right].
\end{array}
\right.
$$

TABLE 35.—*Inverse operations.*

[In Heaviside's system.]

123. Inverse to divergence. $p.\ q.$ scalar:

$$\nabla(pq)=p\nabla q+q\nabla p. \qquad \overset{\prime\prime}{\Sigma}\mathbf{N}pq=\overset{\prime}{\Sigma}\nabla(pq) \quad \therefore\ \overset{\prime\prime\prime}{\Sigma}p\nabla q+\overset{\prime}{\Sigma}q\nabla p=0.$$

124. Inverse to slope. p scalar, $\mathbf{g}$ vector:

$$\operatorname{div}(p\mathbf{g})=p\operatorname{div}\mathbf{g}+\mathbf{g}\nabla p. \qquad \overset{\prime\prime}{\Sigma}\mathbf{N}p\mathbf{g}=\overset{\prime\prime\prime}{\Sigma}\operatorname{div}(p\mathbf{g})\ \therefore\ \overset{\prime\prime\prime}{\Sigma}p\operatorname{div}\mathbf{g}=-\overset{\prime\prime\prime}{\Sigma}\mathbf{g}\nabla p.$$

125. Inverse to curl:

$$\operatorname{curl}(p\mathbf{g})=p\operatorname{curl}\mathbf{g}-V\mathbf{g}\nabla p. \qquad \overset{\prime}{\Sigma}\operatorname{curl}(p\mathbf{g})=\overset{\prime\prime\prime}{\Sigma}V\mathbf{N}p\mathbf{g} \quad \therefore\ \overset{\prime}{\Sigma}p\operatorname{curl}\mathbf{g}=\Sigma V\mathbf{g}\nabla_{\lambda}$$

Integration by parts.

126. $\overset{\prime\prime\prime}{\Sigma}p\nabla\mathbf{q}=-\overset{\prime\prime\prime}{\Sigma}\mathbf{q}\nabla p.$ $\quad\overset{\prime\prime\prime}{\Sigma}p\operatorname{div}\mathbf{g}=-\overset{\prime\prime\prime}{\Sigma}\mathbf{g}\nabla p.$ $\quad\overset{\prime}{\Sigma}p\operatorname{curl}\mathbf{g}=\overset{\prime\prime}{\Sigma}V\mathbf{g}\nabla p.$

127. $\overset{\prime\prime\prime}{\Sigma}\mathbf{f}\operatorname{curl}\mathbf{g}=\overset{\prime}{\Sigma}\mathbf{g}\operatorname{curl}\mathbf{f}.$ $\quad\overset{\prime\prime\prime}{\Sigma}\mathbf{g}\operatorname{div}\mathbf{f}=-\overset{\prime}{\Sigma}\mathbf{f}\nabla\mathbf{g}.$

Differentiating effects of ∇.

128. Case *a.* $\quad \mathbf{N}V\nabla\mathbf{E}=\nabla V\mathbf{EN}\ =\mathbf{E}V\mathbf{N}\nabla=(V\mathbf{N}\nabla)\mathbf{E}.$

b. $\quad \nabla V\mathbf{EH}=\mathbf{E}V\mathbf{H}\nabla\ =\mathbf{H}V\nabla\mathbf{E}\ \therefore\ \operatorname{div}V\mathbf{EH}=\mathbf{H}\operatorname{curl}\mathbf{E}-\mathbf{E}\operatorname{curl}\mathbf{H}.$

c. $\quad \operatorname{curl}V\mathbf{qB}=V\nabla V\mathbf{qB}=\mathbf{q}\nabla\mathbf{B}-\mathbf{B}\nabla\mathbf{q}=\mathbf{q}\operatorname{div}\mathbf{B}+\mathbf{B}\nabla\mathbf{q}-\mathbf{B}\operatorname{div}\mathbf{q}-\mathbf{q}\nabla\mathbf{B}.$

d. $\quad -\operatorname{curl}(\mathbf{E}-\mathbf{e}_o)=\mathbf{K}+\dot{\mathbf{B}}+\mathbf{w}\sigma-\operatorname{curl}V\mathbf{qB}=\mathbf{K}+\dfrac{d\mathbf{B}}{dt}+\mathbf{B}\operatorname{div}\mathbf{q}-\mathbf{B}\nabla\mathbf{q}+(\mathbf{w}-\mathbf{q})\sigma.$

$\quad \operatorname{curl}(\mathbf{H}-\mathbf{h}_o)=\mathbf{C}+\dot{\mathbf{D}}+\mathbf{u}\rho-\operatorname{curl}V\mathbf{qD}\ =\mathbf{C}+\dfrac{d\mathbf{D}}{dt}+\mathbf{D}\operatorname{div}\mathbf{q}-\mathbf{D}\nabla\mathbf{q}+(\mathbf{u}-\mathbf{q})\rho.$

e. $\quad \operatorname{curl}\mathbf{D}P=V\nabla\mathbf{D}P\ =V\nabla\mathbf{D}P-V\mathbf{D}\nabla P=P\operatorname{curl}\mathbf{D}-V\mathbf{D}\nabla P.$

f. $\quad \operatorname{div.}\operatorname{curl}\mathbf{H}=\nabla V\nabla\mathbf{H}\ =0.$

g. $\quad \operatorname{curl}\nabla P=(V\nabla\nabla)P=0.$

h. $\quad (\operatorname{curl})^2\mathbf{A}=V\nabla V\nabla\mathbf{A}=\nabla\,.\,\nabla\mathbf{A}-\nabla^2\mathbf{A}=\nabla\operatorname{div}\mathbf{A}-\nabla^2\mathbf{A}.$

$\quad \nabla^2\mathbf{A}=\nabla\operatorname{div}\mathbf{A}-\operatorname{curl}^2\mathbf{A}.$

i. $\quad \nabla^2P=\operatorname{div}\nabla P.$

TABLE 36.—*Relations between.*

In Heaviside's Units.

	Potential	Slope	Divergence	Curl
129.	pot	$-\nabla$	div	$V\nabla$

Definition , pot $x=\Sigma\frac{x}{4\pi r}$ where x is scalar or vector.

130. pot curl=curl pot. $\qquad$ $\mathrm{curl}^2\ \mathrm{pot}=1$ $\qquad$ $\mathrm{div}=-\nabla$ $\qquad$ $\mathrm{pot}=-\frac{1}{\nabla^2}$

pot div =div pot. $\qquad$ $-\mathrm{pot}\ \nabla\ \mathrm{div}=1$ $\qquad$ $\mathrm{curl}^2=-\nabla^2$ on a circuital vector.

These occur with a vector operand. $\qquad$ $\nabla\ \mathrm{div}=\nabla^2$ on a noncircuital vector.

$\mathrm{div}\ \nabla=\nabla^2$ on a scalar.

Example , $\rho=\mathrm{div}\ \mathbf{F}=-\nabla^2P=-\nabla^2\mathrm{pot}\rho$.

131. *Circuital.*

$$\mathbf{A}_1=\mathrm{pot}\ \mathbf{C}_1=\Sigma\frac{\mathbf{C}_1}{4\pi r}=\Sigma\frac{V(\mathbf{B}_1\mathbf{r}_1)}{4\pi r^2}$$

$$\mathbf{B}_1=\mathrm{curl}\ \mathbf{A}_1=\mathrm{curl\ pot}\ \mathbf{C}_1=\mathrm{pot}\ \mathbf{D}_1=\Sigma\frac{V(\mathbf{C}_1\mathbf{r}_1)}{4\pi r^2}$$

$$\mathbf{C}_1=\mathrm{curl}^2\ \mathbf{A}_1=-\nabla^2\mathbf{A}_1=\mathrm{curl}^2\ \mathrm{pot}\ \mathbf{C}_1=\Sigma\frac{V(\mathbf{D}_1\mathbf{r}_1)}{4\pi r^2}$$

132. *Divergent.*

$$\mathbf{A}_2=\mathbf{P}=\Sigma\frac{\rho}{4\pi r}.\quad=\frac{\mathbf{B}_2.\mathbf{r}_1}{4\pi r^2}.$$

$$\mathbf{B}_2=\mathbf{R}=-\nabla\mathbf{P}=\mathrm{pot}\ \mathbf{D}_2=\Sigma\frac{\mathbf{C}_2.\mathbf{r}_1}{4\pi r^2}.$$

$$\mathbf{C}_2=\mathrm{div}\ \mathbf{R}=4\pi\rho=-\nabla^2\mathbf{A}_2.$$

$$=-\nabla\ \mathrm{div}\ \mathbf{A}_2=\Sigma\frac{\mathbf{D}_2.\mathbf{r}_1}{4\pi r^2}.$$

$\mathbf{r}_1$=the unit vector drawn from ρ to the point where r ends.

Any vector with the suffix 1 is circuital and is the curl of the one before it. It is the potential of the second one after it.

$$\mathbf{B}_1=\mathrm{curl}\ \mathbf{A}_1=\mathrm{pot}\ \mathbf{D}_1=\mathrm{curl\ pot}\ \mathbf{C}_1=\mathrm{pot\ curl}\ \mathbf{C}_1.$$

Any vector with the suffix 2 is the divergent slope of the preceding scalar; any scalar is the divergence of the preceding vector; and whether vector or scalar it is the potential of the one after the next.

$$\mathbf{C}_2=-\nabla\mathbf{B}_2.\quad \mathbf{B}_2=\mathrm{div}\ \mathbf{A}_2.\quad \mathbf{A}_2=\mathrm{pot}\ \mathbf{C}_2.\quad \mathbf{B}_2=\mathrm{pot}\ \mathbf{D}_2.$$

$$\mathbf{133.}\ \mathbf{A}\left\{\begin{array}{lll}\mathbf{A}_1=\mathrm{curl}^2\ \mathrm{pot}\ \mathbf{A}_1 & =\mathrm{curl\ pot}\ \mathbf{B}_1 & =\mathrm{pot}\ \mathbf{C}_1.\\ \mathbf{A}_2=-\mathrm{pot}\ \nabla\ \mathrm{div}\ \mathbf{A}_2= & -\nabla\ \mathrm{pot}\ \mathbf{B}_2 & =\mathrm{pot}\ \mathbf{C}_2.\end{array}\right.$$

$$\mathbf{134.}\ \mathbf{B}\left\{\begin{array}{llll}\mathbf{B}_1=\mathrm{curl}\ A_1 & =\mathrm{curl}^2\ \mathrm{pot}\ \mathbf{B}_1 & =\mathrm{curl\ pot}\ \mathbf{C}_1 & =\mathrm{pot}\ \mathbf{D}_1.\\ \mathbf{B}_2=-\nabla\mathbf{A}_2 & =-\mathrm{pot\ div}\ \mathbf{B}_2 & =-\nabla\ \mathrm{pot}\ \mathbf{C}_2 & =\mathrm{pot}\ \mathbf{D}_2.\end{array}\right.$$

$$\mathbf{135.}\ \mathbf{C}\left\{\begin{array}{lllll}\mathbf{C}_1=\mathrm{curl}^2\ \mathbf{A}_1 & =\mathrm{curl}\ \mathbf{B}_1 & =\mathrm{curl}^2\ \mathrm{pot}\ \mathbf{C}_1 & =\mathrm{curl\ pot}\ \mathbf{D}_1 & =\mathrm{pot}\ \mathbf{E}_1.\\ \mathbf{C}_2=-\nabla^2\mathbf{A}_2 & =-\nabla\mathbf{B}_2 & =-\mathrm{pot}\ \nabla\ \mathrm{div}\ \mathbf{C}_2 & =-\nabla\ \mathrm{pot}\ \mathbf{D}_2 & =\mathrm{pot}\ \mathbf{E}_2.\end{array}\right.$$

$$\mathbf{136.}\ \mathbf{D}\left\{\begin{array}{lllll}\mathbf{D}_1=\mathrm{curl}^3\ \mathbf{A}_1 & =\mathrm{curl}^2\ \mathbf{B}_1 & =\mathrm{curl}\ \mathbf{C}_1 & =\mathrm{curl}^2\ \mathrm{pot}\ \mathbf{D}_1 & =\mathrm{curl\ pot}\ \mathbf{D}_1.\\ \mathbf{D}_2=-\nabla^3\mathbf{A}_2 & =\nabla^2\ \mathrm{div}\ \mathbf{B}_2 & =-\nabla\mathbf{C}_2 & =-\mathrm{pot}\ \nabla\ \mathrm{div}\ \mathbf{D}_2 & =-\nabla\ \mathrm{pot}\ \mathbf{D}_2.\end{array}\right.$$

$$\mathbf{137.}\ \left\{\begin{array}{ll}\mathbf{A}_1=\mathrm{curl}^{-1}\ \mathbf{B}_1 & =\Sigma\frac{V(\mathbf{B}_1\mathbf{r}_1)}{4\pi r^2}.\\ \mathbf{A}_2=\mathrm{div}^{-1}\ \mathbf{B}_2 & =\Sigma\frac{\mathbf{B}_2\mathbf{r}_1}{4\pi r_2}.\end{array}\right.$$

$$\mathbf{138.}\ \left\{\begin{array}{ll}\mathbf{B}_1=\mathrm{curl}^{-1}\ \mathbf{C}_1 & =\Sigma\frac{V(\mathbf{C}_1\mathbf{r}_1)}{4\pi r^2}.\\ \mathbf{B}_2=-\mathrm{div}^{-1}\ \mathbf{C}_2 & =\Sigma\frac{\mathbf{C}_2\mathbf{r}_1}{4\pi r^2}.\end{array}\right.$$

$$\mathbf{139.}\ \left\{\begin{array}{ll}\mathbf{C}_1=\mathrm{curl}^{-1}\ \mathbf{D}_1 & =\Sigma\frac{(V\mathbf{D}_1\mathbf{r}_1)}{4\pi r^2}.\\ \mathbf{C}_2=\mathrm{div}^{-1}\ \mathbf{D}_2 & =\Sigma\frac{\mathbf{D}_2\mathbf{r}_1}{4\pi r^2}.\end{array}\right.$$

$(\mathbf{A}_1.\mathbf{B}_1.\mathbf{r}_1)$, $(\mathbf{B}_1.\mathbf{C}_1\mathbf{r}_1)$, $(\mathbf{C}_1\mathbf{D}_1\mathbf{r}_1)$ are vector systems mutually at right angles to each other.

Vector Potential relations.

(In common units.)

	Electrical.	*Magnetical.*
140. Displacements.	$\mathbf{D}=\frac{c\mathbf{E}}{4\pi}$	$\mathbf{B}=\mu\mathbf{H}$.
141. Vector Potentials.	$-\mathbf{Z}=-c\Sigma\frac{\mathbf{G}}{r}=\Sigma\frac{\text{curl }c\mathbf{E}}{4\pi r}$	$\mathbf{A}=\mu\Sigma\frac{\mathbf{\Gamma}}{r}=\Sigma\frac{\text{curl }\mu\mathbf{H}}{4\pi r}$.
142. Curls.	$-\text{curl }\mathbf{Z}=4\pi\mathbf{D}\quad=c\mathbf{E}$ $-\text{curl }\mathbf{E}=\mu\dot{\mathbf{H}}\quad=4\pi\mathbf{G}$ $\text{curl }c^{-1}\text{ curl }\mathbf{Z}=4\pi\mathbf{G}$	$\text{curl }\mathbf{A}=\mathbf{B}\quad=\mu\mathbf{H}$. $\text{curl }\mathbf{H}=c\dot{\mathbf{E}}\quad=4\pi\mathbf{\Gamma}$. $\text{curl }\mu^{-1}\text{ curl }\mathbf{A}=4\pi\mathbf{\Gamma}$.
143. Energy.	$U=\Sigma\frac{1}{2}\mathbf{ED}\ =\Sigma\frac{1}{2}\mathbf{ZG}$	$T=\Sigma\frac{1}{2}\frac{\mathbf{HB}}{4\pi}=\Sigma\frac{1}{2}\mathbf{A\Gamma}$.
144.	$-\mathbf{Z}=\mathbf{H}+\nabla\Omega$	$-\mathbf{A}=\mathbf{E}+\nabla P$.

145. If $\mathbf{Z}$ and $\mathbf{A}$ are wholly circuital, and

$$\text{div }\mu\dot{\mathbf{Z}}=-4\pi\rho \qquad \text{div }c\dot{\mathbf{A}}=-4\pi\sigma.$$

$$U=\Sigma\frac{\dot{A}c\dot{A}}{8\pi}-\Sigma\tfrac{1}{2}P\sigma \qquad T=\Sigma\frac{\dot{\mathbf{Z}}\mu\dot{\mathbf{Z}}}{8\pi}-\Sigma\tfrac{1}{2}\Omega\rho.$$

TABLE 37.—*Magnetic fields caused by moving electric charges.*

[*Heaviside.* (Phil. Mag. [5] XXXIX, 1889). (In Common Units.)]

146. e = moving charge.

w = velocity parallel to z.

$\mathbf{A}$ = vector potential of moving charge, $=\frac{e\mathbf{w}}{r}=\frac{\mathbf{\Gamma}}{r}$ for $\mu_o=1$.

$\mathbf{H}$ = magnetic force $=\text{curl }\mathbf{A}=-\frac{d\mathbf{A}}{dh}=-\frac{d\mathbf{A}}{dr}\sin\theta$

$$=\frac{e\mathbf{w}\nu}{r^2}\quad=c\mathbf{E}\mathbf{w}\nu.$$

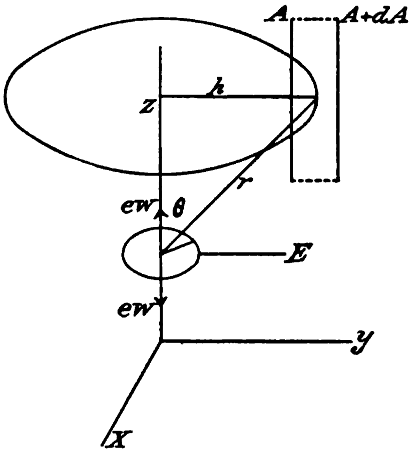

CHART 34.—Vector potential relations.

$\mathbf{H}_o$ = any external magnetic field through which it moves.

$\mathbf{A}_o$ = any vector whose curl $=\mu_o\mathbf{H}_o$

It has no divergence.

$\mathbf{\Gamma}$ = current density of the moving system, a small charged sphere of radius a. $\mathbf{\Gamma}=e\mathbf{w}$.

The polar part of $\mathbf{\Gamma}$ contributes nothing.

Ψ_o = scalar potential of electric forces not due to $\mathbf{A}_o$.

$\mathbf{E}$ = intensity of radial electric force terminating on a small sphere, a.

c = permittivity (electric). μ_o = inductivity (magnetic) of the medium.

v = velocity of propagation. $\mu_o cv^2=1$. $\frac{w}{v}$ is assumed small.

147. 1. A small charged sphere moves parallel to z.

Electric force $c\mathbf{E}=-e\nabla\Psi_o\ =\frac{e}{r^2}$.

Magnetic force $\mathbf{H}=\frac{e\mathbf{w}\sin\theta}{r^2}\ =c\mathbf{E}\mathbf{w}\nu$. $\sin\theta=\nu$, $\cos\theta=\mu$

Magnetic energy $T=\Sigma\frac{1}{2}\mathbf{A\Gamma}=\Sigma\mu_o\frac{\mathbf{H}^2}{8\pi}=\frac{\mu_o e^2\mathbf{w}^2}{8\pi}\int\int\int\frac{\nu^2}{r^2}dr\,d\mu\,d\lambda=\frac{\mu_o e^2\mathbf{w}^2}{3a}$.

Mutual energy of the moving charges and any external field. $M=\Sigma\frac{\mu_o\mathbf{H}_o\mathbf{H}}{4\pi}=\Sigma\mathbf{A}_o\mathbf{\Gamma}=\mathbf{A}e\mathbf{w}$.

Mechanical force on moving charge. $\mathbf{F}$=vector product of moment of convection current and induction of the external field.

$$=\mu_o e\,V\mathbf{wH}_o=-e\frac{d\mathbf{A}_o}{dt}\quad\text{(Lagrangian Eqn. of motion).}$$

148. 2. When the external field is another moving charge.

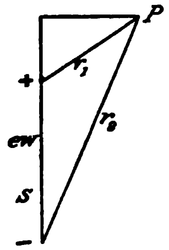

CHART 35.—Moving charge and an external point.

$\mathbf{A}_o$=the vector potential of the current in the second moving system (having no divergence).

$\mathbf{A}_1$=the vector potential of the convection current$=\frac{\mu_o e\mathbf{w}}{r}$.

$\mathbf{A}_2$=the vector potential of the corresponding displacement current $=-\frac{1}{2r}\mu_o ew\nabla\frac{dr}{ds}$.

$$\mathbf{A}=\mathbf{A}_1+\mathbf{A}_2=\mu_o\frac{e}{r}\left(\mathbf{w}-\tfrac{1}{2}w\nabla\frac{dr}{ds}\right)$$

$$M=\mu_o e_1 e_2\left(\mathbf{w}_1\mathbf{w}_2-\tfrac{1}{2}w_1w_2\frac{d^2r}{ds_1ds_2}\right)$$ w_1w_2=velocity of motion in two directions.

$$=\frac{\mu_o e_1e_2w_1w_2}{r}\left(\cos\varepsilon+\frac{1}{2}\frac{d^2r}{ds_1ds_2}\right)$$ (German form) ε=angle between w_1w_2.

$$=\frac{\mu_o e_1e_2w_1w_2}{2r}(2l_1l_2+m_1m_2+n_1n_2)$$ Direction cosines of w_1w_2.

$\mathbf{F}_1=\mu_o e_1\,V\mathbf{w}_1\mathbf{H}_2$. $\mathbf{F}_2=\mu_o e_2\,V\mathbf{w}_2\mathbf{H}_1$, when speeds are constant.

149. 3. Electromagnetic effects of a charge moving in any way.

$w<v$ the velocity of light.

Second circuital law $-\text{curl}\,\mathbf{E}=\mu_o\frac{d\mathbf{H}}{dt}$.

Maxwell's law $\mathbf{J}=\mathbf{C}+\frac{d\mathbf{D}}{dt}+\rho\mathbf{w}$. True current=$\left\{\begin{array}{l}\text{Currents of}\\ \text{conduction }+\\ \text{displacement}+\\ \text{convection.}\end{array}\right.$

First circuital law Curl $\mathbf{H}=c\frac{d\mathbf{E}}{dt}+4\pi\rho\mathbf{w}$ in a nonconducting dielectric.

Electrification $\frac{1}{v^2}\frac{d^2\mathbf{H}}{dt^2}-\nabla^2\mathbf{H}=\text{curl}\,4\pi\rho\mathbf{w}$. Eliminating $\mathbf{E}$, we have,

Impressed force $\frac{1}{v^2}\frac{d^2\mathbf{H}}{dt^2}-\nabla^2\mathbf{H}=\text{curl}\,c\frac{d\mathbf{e}}{dt}$. Since $\rho\mathbf{w}$ becomes $\frac{c}{4\pi}\frac{d\mathbf{e}}{dt}$,

$\frac{1}{v^2}\frac{d^2\mathbf{A}}{dt^2}-\nabla^2\mathbf{A}=4\pi\rho\mathbf{w}$. Since $\mathbf{H}=\text{curl}\,\mathbf{A}$,

Vector potential $\mathbf{A}_o=\frac{4\pi\rho\mathbf{w}}{-\nabla^2}=\Sigma\frac{\rho\mathbf{w}}{r}$.

$$\mathbf{A}=\left(1+\frac{1}{v^2}\frac{d^2}{dt^2}\cdot\nabla^2+\frac{1}{v^4}\cdot\frac{d^4}{dt^4}\nabla^4+\ \ldots\right)\mathbf{A}_o.$$

150. 4. Motion of electrification parallel to the z—axis.

One charge at the point. $\mathbf{w} \,.\, \mathbf{A}_o \,.\, \mathbf{A}$ are all parallel to z.

$\mathbf{A}_o=\frac{e\mathbf{w}}{r}$ $\mathbf{E}$ is radial ; $\mathbf{H}$ is in circles around z.

$$\mathbf{A}=e\,(1+\frac{1}{v^2}\frac{d^2}{dt^2}\cdot\nabla^2+\frac{1}{v^4}\frac{d^4}{dt^4}\Delta^4+\;.\;.\;)\frac{\mathbf{w}}{r} \text{ at distance } r \text{ from } e.$$

$$=\frac{e\mathbf{w}}{r}\left[1+\frac{w^2}{v^2}\cdot\frac{\nu^2}{2}(1+\frac{w^2}{v^2}\frac{3}{4}\nu^2(1+\frac{w^2}{v^2}\frac{5}{6}\nu^2(1+\;.\;.\;\right]=\frac{ew}{r}\left(1-\frac{w^2\nu^2}{v^2}\right)^{-\frac{1}{2}}$$

$$\mathbf{H}=-\frac{d\mathbf{A}}{dh}=-\nu\frac{d\mathbf{A}}{dr}+\frac{\mu\nu}{r}\frac{d\mathbf{A}}{d\mu}=\frac{e\mathbf{w}\nu}{r^2}\left(1+\mu\frac{d}{d\mu}\right)\left(1-\frac{w^2}{v^2}\nu^2\right)^{-\frac{1}{2}}$$

$$c\mathbf{E}=\frac{e}{r^2}\,\frac{1-\frac{w^2}{v^2}}{\left(1-\frac{w^2\nu^2}{v^2}\right)^{3/2}}. \qquad \mathbf{H}=c\mathbf{E}\mathbf{w}\nu=\frac{e\mathbf{w}}{r^2}\nu.$$

a. As the speed w increases the electro-magnetic field concentrates itself more and more about the equatorial plane $\theta=90^\circ$. To give an idea of the accumulation, let $\frac{w^2}{v^2}=.99$; then $c\mathbf{E}=\frac{1}{100}$ of the normal value of $\frac{e}{r^2}$ at the pole, and 10 times the normal value at the equator. The latitude where the value is normal is given by $\nu=\sin\theta=\frac{v}{w}\left[1-(1-\frac{w^2}{v^2})^{2/3}\right]^{1/2}$.

b. When $w=v$, the velocity of light, the solution is a plane electro-magnetic wave in the equatorial plane, $\mathbf{E}$ and $\mathbf{H}$ being zero everywhere else.

151. 5. Charge of linear density e distributed along a straight line and moving in its own direction.

Make the medium conduct electrically and magnetically, with equal rates of subsidence, ε^{-pt} diminishing to zero.

R=resistance; L=inductance; K=leakage-conductance; S=permittance; C= current; V_1=potential difference, that is transverse *E. M. F.* from wire to wire, and not the electrostatic difference of potential.

$$\mathbf{H}=c\mathbf{E}\;v=\frac{2e}{r}\cdot v.$$

$$-\frac{dV_1}{dz}=\left(R+L\frac{d}{dt}\right)C. \qquad -\frac{dC}{dz}=\left(K+S\frac{d}{dt}\right)V_1.$$

$\mathbf{E}_1=z$-component of $\mathbf{E}$. $\mathbf{E}_2=h$-component of $\mathbf{E}$.

$$\frac{1}{h}\cdot\frac{d}{dh}(h\mathbf{H})=-cw\frac{d\mathbf{E}_1}{dz}. \qquad -\frac{d\mathbf{H}}{dz}=-cw\frac{d\mathbf{E}_2}{dz}.$$

$$\mathbf{H}=cw\,\mathbf{E}_2.$$

$$\frac{d\mathbf{E}_1}{dh}-\frac{d\mathbf{E}_2}{dz}=-\mu_o w\frac{d\mathbf{H}}{dz}. \qquad \frac{d\mathbf{E}_1}{dh}=\left(1-\frac{w^2}{v^2}\right)\frac{d\mathbf{E}_2}{dz}.$$

The displacement outward through any spherical surface with charge e at the center $=e$.

152. 6. Electrification parallel to z; speed w parallel to z; e is any function of z.

If $w=v$, $\mathbf{E}_1=0$ parallel to z, $\mathbf{E}_2=\mu v\mathbf{H}=\mathbf{E}$ perpendicular to z,

$$\frac{1}{h}\frac{d}{dh}(h\mathbf{H})=0.$$

If the electrification is on the axis z.

$$\frac{\mathbf{E}}{\mu v}=\mathbf{H}=\frac{2ev}{r}.$$

153. 7. Perfectly conducting sphere of radius a and charge e moving steadily along z at the speed w. $r=a$. $w<v$.

$$U=\text{Tctal electric energy}=\frac{e^2}{2ca}\cdot\frac{1-\frac{w^2}{v^2}}{4}\left[1+\frac{\frac{3}{2}}{1-\frac{w^2}{v^2}}+\frac{\frac{3}{2}\tan^{-1}\frac{w}{v}\left(1-\frac{w^2}{v^2}\right)^{-\frac{1}{2}}}{\frac{w}{v}\left(1-\frac{w^2}{v^2}\right)^{\frac{3}{2}}}\right]$$

$$T=\text{Total magnetic energy}=\frac{e^2}{2ca}\cdot\frac{1-\frac{w^2}{v^2}}{4}\left[1+\frac{2\frac{w^2}{v^2}-\frac{1}{2}}{1-\frac{w^2}{v^2}}+\frac{\left(2\frac{w^2}{v^2}-\frac{1}{2}\right)\tan^{-1}\frac{w}{v}\left(1-\frac{w^2}{v^2}\right)^{-\frac{1}{2}}}{\frac{w}{v}\left(1-\frac{w^2}{v^2}\right)^{\frac{3}{2}}}\right]$$

154. 8. Case when $w>v$. Charge moves with velocity greater than light.

1. There is no disturbance in front of the charge.
2. Conical wave surfaces of angle, $\sin\beta=\frac{v}{w}$, trail behind.

Compare the original paper for this important and difficult case.

155. 9. Straight line changed to linear density e and moving in its own line.

$$H=-\frac{dA}{dh}.$$

At point P. $$A=ew\log\left(\frac{r_1}{r_2}\cdot\frac{w_1+\left(1-\nu_1^2\frac{w^2}{v^2}\right)^{\frac{1}{2}}}{w_2+\left(1-\nu_2^2\frac{w^2}{v^2}\right)^{\frac{1}{2}}}\right)$$

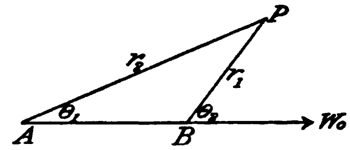

CHART 36.—Moving charged line and external point.

$$H=ew\left(1-\frac{w^2}{v^2}\right)\left[\frac{\nu_1}{r_1\left(1-\nu_1^2\frac{w^2}{v^2}\right)+r_1\mu_1\left(1-\nu_1^2\frac{w^2}{v^2}\right)^{\frac{1}{2}}}-\text{same function of } r_2\mu_2\nu_2.\right]$$

Where $\nu=\sin\theta$ and $\mu=\cos\theta$.

When P is vertically over B, and A is at an infinite distance, $H=\frac{ew}{h}$.

This is one-half the value due to an infinitely long straight current ew.

If $w=v$, $H=0$ unless $\nu_1=1$.

If P is to the left of B we must add the electrification which is ahead of P.

When P is in the middle of an infinitely long line, $H=2\frac{ew}{h}$.

156. 10. Straight line moving perpendicular to its length.

$$A=\frac{ew}{\left(1-\frac{w^2}{v^2}\right)^{\frac{1}{2}}}\log\frac{x_1+\left[x_1^2+y^2+z^2\left(1-\frac{w^2}{v^2}\right)^{-1}\right]^{\frac{1}{2}}}{x_2+\left[x_2^2+y^2+z^2\left(1-\frac{w^2}{v^2}\right)^{-1}\right]^{\frac{1}{2}}}.$$

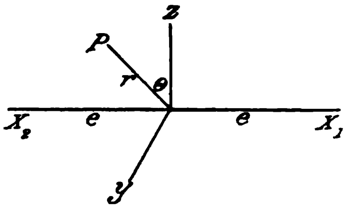

CHART 37.—Moving perpendicular to its length.

When x_1x_2 is infinite,

$$cE=\frac{2e}{r}\frac{\left(1-\frac{w^2}{v^2}\right)^{\frac{1}{2}}}{\left(1-\nu^2\frac{w^2}{v^2}\right)}.\qquad H=cEw\nu.$$

E is radial to line.
H is parallel to line.

Terminating the field internally at $r=a$ we have the case of a charged cylinder moving perpendicular to its length. When $w=v$, E and H disappear everywhere except on the plane $\theta=90^\circ$.

157. 11. Plane charged to density e and moving perpendicular to itself.

$$H=\frac{ew}{\left(1-\frac{w^2}{v^2}\right)^{\frac{1}{2}}}\log\frac{r_1^2-y_1^2\frac{w^2}{v^2}}{r_2^2-y_2^2\frac{w^2}{v^2}}$$

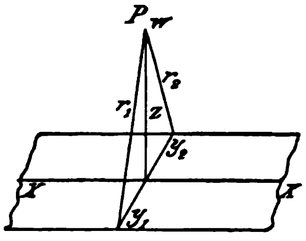

CHART 38.—Charged plane moving perpendicular to itself.

When P is equidistant from the edges $r_1=r_2$, $H=0$.
There is no H due to an infinitely large plane charged e.
The displacement current is the negative of the convection current at the same place and there is no true current.
$E_1=z-$component of E; $E_2=$component parallel to the plane.

$$cE_1=2e\left[\tan^{-1}\frac{y_1}{z}\left(1-\frac{w^2}{v^2}\right)^{\frac{1}{2}}-\tan^{-1}\frac{y_2}{z}\left(1-\frac{w^2}{v^2}\right)^{\frac{1}{2}}\right].\qquad E_2=\frac{H}{cw}.$$

When the plane is infinite , $H=0$, $E_2=0$; $cE_1=cE=2\pi e$.

158. 12. Charged plane moving in its own plane.

$$H=2ew\left[\tan^{-1}\frac{z}{h\left(1-\frac{w^2}{v^2}\right)^{\frac{1}{2}}}\right]_{z_1}^{z_2}.$$

z_1z_2 are the extreme values of z measured parallel to the breadth of the plane.

$+H=2\pi ew$ above plane if infinite; $-H=2\pi ew$ below plane.
Compare J. J. Thomson, Phil., May, July, 1889.

TABLE 38.—*The conduction of electricity through gases by charged ions.*

J. J. THOMPSON'S SOLUTION FOR A STEADY STATE OF THE GAS.

159. q=the number of positive and negative ions each, produced in unit volume and in unit time.

n_1=the number of positive ions per unit volume.

n_2=the number of negative ions per unit volume.

$n_1 n_2$ is proportional to the number of collisions in the unit time.

$\alpha n_1 n_2$=the number that disappear by recombination to form an electrically neutral system.

e=the electric charge carried by each ion.

X=the electric force parallel to x, along the line of discharge.

$k_1 X$=the velocity of the positive ion.

$k_2 X$=the velocity of the negative ion; equal to, greater, or much greater than that of the positive ions.

i=the movement of the ions under the electric forces, or the current through the unit area of the gas, neglecting diffusion not due to the electric field.

160. Electric slope. $\frac{dX}{dx}=4\pi\,(n_1-n_2)\,e=4\pi\times$ volume density of electrification.

161. Movement. $i=k_1 n_1 eX+k_2 n_2 eX.$ Constant in steady state of gas.

162. Pos. and neg. vol. density. $n_1 e=\frac{1}{k_1+k_2}\left(\frac{i}{X}+\frac{k_2}{4\pi}\frac{dX}{dx}\right).$ $n_2 e=\frac{1}{k_1+k_2}\left(\frac{i}{X}-\frac{k_1}{4\pi}\frac{dX}{dx}\right).$

163. Excess of ionization above recombination. $\frac{d}{dx}(k_1 n_1 X)=q-\alpha n_1 n_2.$ $-\frac{d}{dx}(k_2 n_2 X)=q-\alpha n_1 n_2.$

164. General equation.

$$\frac{1}{4\pi e}\cdot\frac{k_1 k_2}{k_1+k_2}\cdot\frac{d}{dx}\left(X\frac{dX}{dx}\right).$$
$$=q-\frac{\alpha}{X^2 e^2\,(k_1+k_2)^2}\left(i+\frac{k_2}{4\pi}X\frac{dX}{dx}\right)\left(i-\frac{k_1}{4\pi}X\frac{dX}{dx}\right).$$

165. Auxiliaries. $X^2=2y;$ $\frac{dy}{dx}=p;$ Take q=const; $k_1=k_2=k;$ Integrate.

166. Solution. $\frac{k^2}{16\pi^2}p^2-i^2=\frac{qek}{\pi\left(1-\frac{\alpha}{8\pi ek}\right)}y+C\,(2y)^{\frac{\alpha}{8\pi ek}}$ C=const. of integration.

The steady state is unstable and breaks up into luminous striæ.

MODIFIED EQUATION BY J. H. JEANS.

Introduce expressions for new forces of repulsion, elasticity, etc., such that q and α are functions of X at the point measured; q and α are single valued functions of y and p.

167. Thomson's equation. $\frac{1}{4\pi e}\cdot\frac{k_1 k_2}{k_1+k_2}\frac{d^2y}{dx^2}=q-\frac{\alpha}{2ye^2\,(k_1+k_2)}\left(i+\frac{k_2}{4\pi}p\right)\left(i-\frac{k_1}{4\pi}p\right).$

168. Jeans' equation. $\frac{1}{4\pi e}\cdot\frac{k_1 k_2}{k_1+k_2}p\frac{dp}{dy}=q+\frac{\alpha k_1 k_2}{32\pi^2 e^2\,(k_1+k_2)^2 y}\left[p^2-4\pi i\left(\frac{1}{k_1}-\frac{1}{k_2}\right)p-\frac{16\pi^2 i^2}{k_1 k_2}\right].$

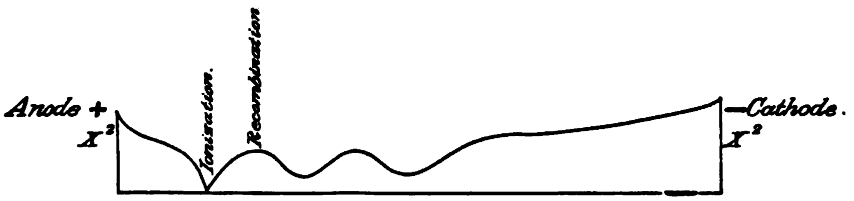

CHART 39.—The minima and maxima of ionization.

References: J. J. Thomson, Phil. Mag., March, 1899; J. H. Jeans, Phil. Mag., March, 1900

Ionization occurs at the minima, and recombination at the maxima of curve.

Thomson's equation gives sharp and Jeans' rounded minima.

Since luminous striæ occur at the places of recombination, it is probable that the visible coronal and auroral rays mark the places of recombination of the ions, and the dark interspaces those of ionization at the sun and earth, respectively. There is an excessive density of ions in the luminous striæ.

THEORY OF THE NEGATIVE GLOW, THE DARK SPACE, AND THE POSITIVE COLUMN.

[J. J. Thomson, Phil. Mag., April, 1901.]

169. λ=mean free path of a corpuscle.

$Xe\lambda$=work done on it by the electric field=mean kinetic energy acquired.

f=fraction of whole number of collisions leading to ionization.

β=fraction of collisions leaving corpuscles sticking to molecules.

u=average velocity of negative corpuscle$=k_2\sqrt{X}$ (instead of k_2X).

v= " " " positive corpuscle$=k_1\sqrt{X}$ (instead of k_1X).

n_2=number of negative corpuscles.

n_1= " " positive " .

Notation changes m to n_1, n to n_2, k_1 to k_2, k_2 to k_1 to reduce this paper to the preceding.

$\frac{\lambda}{u}$=the interval between two collisions.

$n_2\frac{u}{\lambda}$=total number of collisions in unit time per unit volume.

$n_2\frac{u}{\lambda}f(Xe\lambda)$=number of ions produced in unit volume per second.

$n_2\frac{u}{\lambda}\beta$ =number of ions which disappear in unit volume per second.

$\frac{n_2u}{\lambda}\Big[f(Xe\lambda)-\beta\Big]$=rate at which the ions increase per unit volume.

The axis x is positive from the cathode to the anode.

The electric force X is directed from the anode to the cathode.

170. $$\frac{dn_2}{dt}+\frac{d(n_2u)}{dx}=\frac{n_2u}{\lambda}\Big[f(Xe\lambda)-\beta\Big].$$

$\frac{dn_2}{dt}=0$ for steady state.

$\frac{d(n_2u)}{dx}=0$ for uniform column.

171. $$i=n_1v+n_2u=n_1k_1\sqrt{X}+n_2k_2\sqrt{X}.$$

This differs from 161 by assuming the velocity proportional to $\sqrt{X}$ instead of to X, and making $e=1$.

Since kinetic energy$=X\lambda=\frac{1}{2}mv^2$. $v=\sqrt{\frac{2\lambda}{m}}\quad\sqrt{X}=k_1\sqrt{X}$.

172. $$\frac{dX}{dx}=-4\pi\rho=-4\pi\,(n_1-n_2)e\ .\ \rho=\text{volume density of electrification.}$$

173. $$n_2u=\frac{n_2k_2\sqrt{X}}{k_1+k_2}=\frac{k_2i}{k_1+k_2}+\frac{k_1k_2}{4\pi e}\cdot\frac{\sqrt{X}}{k_1+k_2}\cdot\frac{dX}{dx}.$$

174. $$\frac{d(n_2u)}{dx}=\frac{k_1k_2}{4\pi e}\cdot\frac{2}{3}\frac{d^2X^{3/2}}{dx^2}=\frac{n_2u}{\lambda}\Big[f(Xe\lambda)-\beta\Big].$$

$$=\left[\frac{k_2}{k_1+k_2}\frac{i}{\lambda}+\frac{2}{3}\frac{k_1k_2}{4\pi e\lambda(k_1+k_2)}\frac{dX^{3/2}}{dx}\right]\Big[f(Xe\lambda)-\beta\Big].$$

175. When $f(Xe\lambda)-\beta$ is positive, $X>X_o$. X_o=value of X in the uniform positive column.

" " $\frac{d^2X^{3/2}}{dx^2}$ is positive.

" " graph of $X^{3/2}$ is convex to axis x.

Rule: $X^{3/2}$ is $\begin{Bmatrix}\text{convex}\\ \text{concave}\end{Bmatrix}$ to axis x according as $\begin{Bmatrix}X>X_o.\\ X<X_o.\end{Bmatrix}$

The electric force is $\begin{Bmatrix}\text{increasing}\\ \text{diminishing}\end{Bmatrix}$ toward the anode according to excess of $\begin{Bmatrix}\text{positive}\\ \text{negative}\end{Bmatrix}$ ions at the point of observation.

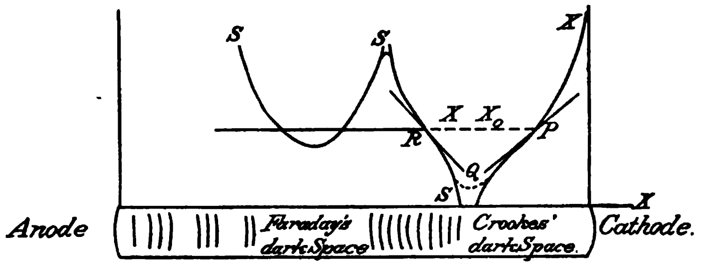

CHART 40.—Critical points on the electric force in discharge tubes.

Two cases. Tangent parallel to x, or not.

R . P=points of tangency.

Q=ionization exceeds recombination.

S . S=points of unsteadiness.

TABLE 39.—*The Zeeman effect.*

ELECTRO-MAGNETIC UNITS.

[Zeeman, Lamor, Preston, Michelson, Cornu, Lorentz, Reese.]

The general equations of motion of a particle which describes an ellipse about the axis (l . m . n) under a force directed toward its center k_1^2r, with perturbing forces which rotate the ellipse in its own plane with the angular velocity ω, and oscillate the plane itself.

176.

Acceleration.	Elastic resistance.	Mechanical deflection.	Centrifugal component in plane.	Centrifugal force from component perpendicular to the plane.
$\ddot{x}=$	$-k_1^2x$	$+2\omega\,(n\dot{y}-m\dot{z})$	$+\omega^2x$	$-\omega^2l\,(lx+my+nz).$
$\ddot{y}=$	$-k_1^2y$	$+2\omega\,(l\dot{z}-n\dot{x})$	$+\omega^2y$	$-\omega^2m\,(lx+my+nz).$
$\ddot{z}=$	$-k_1^2z$	$+2\omega\,(m\dot{x}-l\dot{y})$	$+\omega^2z$	$-\omega^2n\,(lx+my+nz).$

177. ω=angular velocity of the axes of the ellipse about (l . m . n)

The elastic resistance is directed toward the center.

The deflecting force, 2ω . q sin θ, acts perpendicular to the plane q . (l . m . n) where q makes the angle θ with the axis of rotation.

The centrifugal force has a component in the plane of rotation and another perpendicular to it; they produce a rotation of the apsides and an oscillation of the plane, if periodic.

Compare equations of the International Cloud Report (155), (167), (181), (228), etc.

All these motions combined, if periodic, produce the entire series of the multiple lines of the Zeeman effect.

If the velocity q and also the axis (l . m . n) coincide with z, since (l . m . n)=(0 . 0 . 1) we have with and without centrifugal force.

178. $\ddot{x}=-(k_1^2-\omega_3^2)x+\omega_3 2\dot{y}.$ $\ddot{x}=-k_1^2x+2\omega_3\dot{y}.$

$\ddot{y}=-(k_1^2-\omega_3^2)y-2\omega_3\dot{x}.$ $\ddot{y}=-k_1^2y-2\omega_3\dot{x}.$

$\ddot{z}=-k_1^2z.$ $\ddot{z}=-k_1^2z.$

179. Frequencies, Unmodified. $n=\frac{1}{T}=\frac{k_1}{2\pi}=\frac{k}{2\pi\sqrt{m}}$. m=mass moved.

Modified. $n_1=\frac{1}{T_1}=\frac{p_1}{2\pi}=\frac{k}{2\pi\sqrt{m}}\left(1\mp\frac{eH}{2k\sqrt{m}}\right)$.

180. The sign — is for positive rotation with period less in field.,
The sign + is for positive rotation with period greater in field.
Periodic times, Unmodified$=T$; Modified$=T_1$.

181. Ratio $\frac{\Delta T}{T}=\frac{T\frac{eH}{2k\sqrt{m}}}{T}=\frac{e}{m}\cdot\frac{HT}{4\pi}$.

All motions of the ion can be resolved into linear vibrations parallel to the lines of force with two circular vibrations, right-handed and left-handed, perpendicular to the lines of force.

182. *Solution.* $(x\,.\,y\,.\,z)=(x_o\,.\,y_o\,.\,z_o)e^{ipt}=(x_o\,.\,y_o\,.\,z_o)e^{st}$. Take $\omega^2=0$.
If the unmodified principal vibration is a linear oscillation parallel to z.

183. $(x\,.\,y)=(x_o\,.\,y_o)e^{ipt}\quad=(x_o\,.\,y_o)e^{st}$.

$s^2x_o=-k_1^2x_o+2\omega sy_o$.

$s^2y_o=-k_1^2y_o-2\omega sx_o$.

184. If $\omega=0$ $\quad s^2=-p^2=-k_1^2 \quad p=k_1 \quad s=ip=ik_1$.

185. If ω is not $=0$ $\quad (p^2-k_1^2)^3-b^2p^2(p^2-k_1^2)\quad=0 \quad 2\omega=b$.

$(p^2-k_1^2)\Big[(p^2-k_1^2)^2-b^2p^2)=0$.

$p=k_1$.

$p^2-k_1^2=\pm bp$.

$p=k_1+\frac{b^2}{8k}\pm\frac{1}{2}b$ $\quad$ Take $b^2=0$, $\quad k_1=\frac{k}{\sqrt{m}}$, $\quad b=\frac{eH}{m}=2\omega$.

186. $p=k_1\pm\omega=\frac{k}{\sqrt{m}}\pm\frac{eH}{2m}$

The original periodic motion, $p=k_1$, is modified into a doubly periodic motion $p+\omega$ and $p-\omega$.

Hence, the magnetic force H, acting on $\frac{e}{m}$ moving in an ellipse, rotates the ellipse with the angular velocity $2\omega=\frac{eH}{m}$.

The motion is unmodified.

187. The rotating ellipse. $x=a\cos k_1t$. $\quad y=b\sin k_1t$. $\quad$ Where $k_1=2\pi n$.

The motion is modified by the angular velocity ω.

188. $\begin{cases}x=a\cos k_1t\cos\omega t-b\sin k_1t\sin\omega t.\\ y=a\cos k_1t\sin\omega t+b\sin k_1t\cos\omega t.\end{cases}$ By composition,

189. $\begin{cases}x=\frac{1}{2}(a+b)\cos(k_1+\omega)t+\frac{1}{2}(a-b)\cos(k_1-\omega)t=x_1+x_2.\\ y=\frac{1}{2}(a+b)\sin(k_1+\omega)t-\frac{1}{2}(a-b)\sin(k_1-\omega)t=y_1+y_2.\end{cases}$

The resultant motion is equivalent to two opposite circular motions of frequencies $n+n_1$ and $n-n_1$.

190. The term in z may be taken doubly periodic:

$$z = a \sin n_1 t \sin k_1 t = \frac{a}{2}\Big[\cos (k_1 - n_1)t - \cos (k_1 + n_1)t\Big].$$

This represents two vibrations of equal amplitude and frequencies, $\frac{k_1 - n_1}{2\pi}$ or $\frac{k_1 + n_1}{2\pi}$, required for the quartet.

The sextet and other complex vibrations are formed by evaluation of the perturbing forces which were neglected above in terms of ω^2.

Thus the rotation of the orbits of the triplets around the line of apsides in addition converts the group into a sextet. Variations of this principle contribute to form the several types of widenings and groupings that have been observed.

191. The circular or elliptical motions of the ion m is accelerated by adding the component of the circular magnetic rotation.

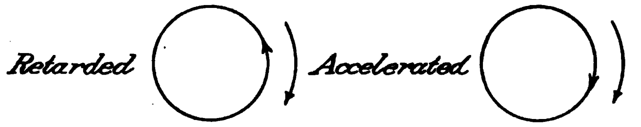

CHART 41.—Retardation and acceleration of a rotating ion.

192. The single spectrum line is split up into a triplet when viewed *across* the lines of the magnetic field and each is plane polarized, A and C parallel to the field and B at right angles to it. A Nichol prism parallel to the field cuts out A and C; at right angles to the field it cuts out B. The line B is twice as bright as A or C.

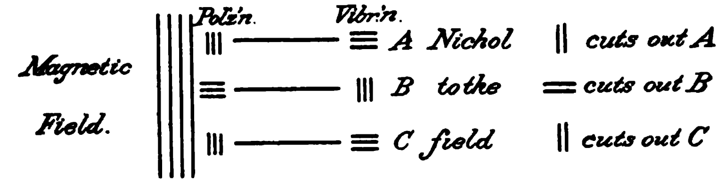

CHART 42.—Polarization viewed across a magnetic field.

193. The single spectrum line is converted into a doublet when viewed *along* the magnetic field. One component is circularly polarized left-handed; the other is circularly polarized right-handed; the missing middle line has vibrations seen end on which are indistinguishable.

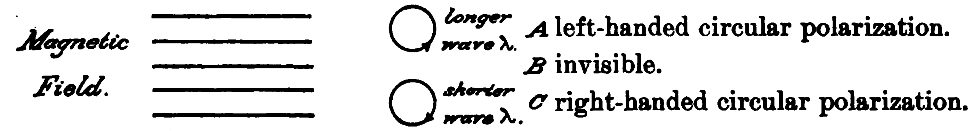
Magnetic
Field.
longer wave λ.
shorter wave λ.
A left-handed circular polarization.
B invisible.
C right-handed circular polarization.

CHART 43.—Polarization viewed along a magnetic field.

194. The ratio $\frac{e}{m}$ is of the order 10^7 electro-magnetic C.G.S. units.

The mass of the ion is $\frac{1}{1000}$ the mass of the atom. There are probably 1,000 electrons in an atom. The total structure of the molecule has the ions vibrating about its center in circular, elliptical, or more complex orbits which are disturbed by immersion in a magnetic field in accordance with these mathematical principles.

References.—Zeeman.	Phil. Mag.	Mar., 1897;	Astrophys.	Jan., 1899.
Lamor.	Phil. Mag.	Dec., 1897.		
Preston.	Phil. Mag.	Apr., 1898;	Phil. Mag.	Feb., 1899.
Michelson.	Astrophys.	June, 1897;	Astrophys.	Feb., 1898.
Cornu.	Astrophys.	Dec., 1897;	Astrophys.	Mar., 1898.
Lorentz.	Astrophys.	Jan., 1899.		
Reese.	Astrophys.	June, 1898;	Astrophys.	Sept., 1900.

TABLE 40.—*Shifting and broadening of spectrum lines.*

[Jewell—Humphreys—Mohler—Wilson—Wilsing—Godfrey.]

195. General law.

$$\triangle\lambda = a\,.\,b\ .\ \lambda\,(B-B_o).$$

$$=\frac{\alpha\sqrt[3]{v}}{T_m}\begin{Bmatrix}1\\2\\3\end{Bmatrix}.\ \lambda\,(B-B_o).$$

$$=\frac{\alpha\sqrt[3]{\frac{m}{\rho}}}{T_m}\begin{Bmatrix}1\\2\\3\end{Bmatrix}.\ \lambda\,(B-B_o).$$

λ=wave length.
α=coef. of linear expansion.
v=atomic volume.
m= " mass.
ρ= " density.
T_m=absolute temperature of the melting point.
B=barometric pressure.
b is proportional to the Mendeljeff series:
  1=Principal.
  2=First subordinate.
  3=Second subordinate.

196. Shift in the different orders of spectrum.

$$\frac{\lambda\ .\ \text{3d Spect}}{\lambda\ .\ \text{2d Spect}}=\frac{2}{3};\qquad \frac{\triangle\lambda\ .\ \text{3d Spect}}{\triangle\lambda\ .\ \text{2d Spect}}=\frac{3}{2}.$$

$$\lambda\ .\ \triangle\lambda\ .\ \text{2d}=\lambda\ .\ \triangle\lambda\ .\ \text{3d}=\text{Const.}$$

197. Constant product.

$$T_m\ .\ \alpha\ .\ \sqrt[3]{v}=T_m\ .\ \alpha\ .\ \sqrt[3]{\frac{m}{\rho}}=48600.$$

Reducing to wave length 4,000 and 12 atmospheres.

198. The average shift. $\triangle\lambda=0.010$ Ångström unit per atmosphere toward the red.

It varies for different elements.

199. Physical conditions.

	An increase of		
	Temperature.	Density.	*Pressure.*
Increases the	Number of lines and intensity.	Width symmetrically or unsymmetrically.	Shift or change in wave length.

Hence the Michelson standard wave lengths, cadmium red, green, blue, are essentially *relative.* They differ .208 .173 .186 Ångst. U. from Rowland's.

THEORETICAL EXPLANATIONS OF THE EFFECT.

200. General view. v Lommel: The damping is due to resistance of medium.

Wilsing's extension: In addition, the moment of inertia is increased by the internal friction of the medium as Bessel and Stokes show in pendulum vibrations.

Godfrey: Gives the analogue of a vibrating plate.

General equation. v Lommel: A damped simple harmonic vibration subject to the periodic impulse $-F\sin qt$, where x= distance of the moving m from point of equilibrium.

201. 1st form.

$$m\frac{d^2x}{dt^2}+K\frac{dx}{dt}+Ax+Bx^2+Cx^3+\ \ldots\ +F\sin qt=0.$$

202. 2d form.

$$\frac{d^2x}{dt^2}+\frac{K}{m}\frac{dx}{dt}+\frac{A}{m}x+\frac{B}{m}x^2+\frac{C}{m}x^3+\ \ldots\ +\frac{F}{m}\sin qt=0.$$

203. 3d form.

$$\frac{d^2x}{dt^2}+2k\frac{dx}{dt}+p^2x+b\varepsilon x^2+c\varepsilon^2x^3+\ \ldots\ +f\sin qt=0.$$

204. Coefficients. k=damping; be and $c\epsilon^2$=fluorescence.

f=amplitude of the excitant vibration of period $\frac{\pi}{q}$.

205. Periods. $\frac{\pi}{p}$=period of undamped vibration.

$\frac{\pi}{r}=\frac{\pi}{\sqrt{p^2-k^2}}$=damped vibration.

$\frac{\pi}{q}$=period of excitant vibration.

$\frac{\pi}{\mu_0}$=period of maximum intensity vibration.

206. Two physical theories: Dynamical, with changes in molecular or atomic vibrations.
Electromagnetic, with changes in the vibrations of electric charges and specific inductive capacity of the medium.

207. Wilsing's extension.

$$\frac{d^2x}{dt^2}+\frac{2k}{1+\gamma}\frac{dx}{dt}+\frac{p^2}{1+\gamma}x \quad + \ . \ . \ . \quad +\frac{f}{1+\gamma}\sin qt=0$$

208. Acoustical analogue. Rayleigh-Godfrey.

$$\frac{d^2x}{dt^2}+\frac{\frac{\rho\pi p^2R^3}{3M}}{1+\frac{8\rho R^3}{3M}}+\frac{p^2}{1+\frac{8\rho R^3}{3M}}+ \ . \ . \ . \qquad =0$$

$$\gamma=\frac{8\rho R^3}{3M} \qquad 2k=\frac{\rho\pi p^2R^3}{3M}$$

ρ=density of air.
M=mass of disk.
c=velocity of sound.
R=radius of disk.
λ=wave length of emitted rays.

209. Solution. (v. Lommel:) $x=M\sin(qt-\alpha)+Ne^{kt}\sin(rt+\psi)$.

(Wilsing:) $x=M\sin(qt-\alpha)+Ne^{-\frac{kt}{1+\gamma}}\sin(rt+\psi)$.

210. Molecular absorption. (v. Lommel:) $\Delta=\frac{mf^2\sin^2\alpha}{16k^3}$; $\tan\alpha=\frac{2kq}{p^2-q^2}$.

If $k_1=\frac{k}{1+\gamma}$, $f_1=\frac{f}{1+\gamma}$, $p_1^2=\frac{p^2}{1+\gamma}$, γ=damping coefficient.

(Wilsing:) $\Delta=\frac{mf_1^2}{16k_1^2}\sin^2\alpha$; $\tan\alpha=\frac{2k_1q}{p_1^2-q^2}$.

$$d\Delta=\frac{m}{2}\left(\int_0^t\left(\frac{dx}{dt}\right)^2dt-\left\{\int_0^t\left(\frac{dx}{dt}\right)^2dt\right\}_{f=0}\right).$$

211. Maximum absorption or place of brightest line. When $q^2=p^2$ by v. Lommel's theory.

When $q^2=p_1^2=\frac{p^2}{1+\gamma}$ by Wilsing's theory.

The relative displacement toward the red

$$\frac{\pi}{p_1}-\frac{\pi}{p}=\frac{\pi\gamma}{2p}$$

If γ^2 and $\left(\frac{k_1}{p}\right)^2$ can be neglected, the bright lines and the absorption lines are shifted equally.

212. Noncoincidence of the max. with the main vibration.

$$e^{-k_1t}\sin r_1t=\frac{4k_1r_1}{\pi}\int_0^\infty\frac{\mu}{(k_1^2+r_1^2+\mu^2)^2-4r_1^2\mu^2}\sin\mu t\,d\mu.$$

213. Amplitude of period $\frac{\pi}{\mu}$. $$f_{\mu}=\frac{4kr_1}{\pi}\,\frac{\mu}{(k^2+r_1^2+\mu^2)^2-4r_1^2\mu^2}.$$

$\frac{\pi}{\mu_o}$ $$\left(\frac{dg}{d\mu}\right)_{\mu=\mu_o}=0 \qquad \mu_o^2=\tfrac{1}{3}(p_1^2-2k^2)+\tfrac{2}{3}(p_1^4-p_1^2k^2+k^4)^{\frac{1}{2}}$$

$$\mu_o^2=r_1^2+\frac{k^4}{4p_1^2}+\cdots$$

$$r_1=\sqrt{p_1^2-k_1^2}=\sqrt{\frac{p^2}{1+\gamma}-\left(\frac{k}{1+\gamma}\right)^2}, \qquad \text{If } \left(\frac{k_1}{p}\right)^2=0.$$

214. Main amplitude. $$f_{p1}=\frac{4kp_1}{\pi}\cdot\frac{\mu}{(p_1^2-\mu^2)^2}.$$

$$f_{\mu}^2:f_{p1}^2=I_{\mu}:I_{p1}$$ Hence lines are shifted but are not perceptibly wider.

215. Electrical analogue. $$\triangle\lambda=\lambda_r-\lambda_p=\gamma\frac{B}{2}\cdot\lambda_r \qquad \lambda_r=4.10^{-4}\text{mm. for } \frac{\pi}{r}$$

$$=2.10^{-8} \qquad \lambda_p= \qquad \text{for } \frac{\pi}{p}$$

$\left(\frac{k}{p}\right)^2$ vanishes for no broadening; $B=12$ atmospheres.

$\left(\frac{k}{p}\right)^2$ is sensible for fluorescence. $\gamma=8.10^{-6}$

TABLE 41.—*The radiation function in the spectrum.*

[Stefan—Wien—Paschen—Nutting.]

216. General form of the function. 1. $J=ae^{-\frac{b}{T}}$. λ=wave length in μ.

217. For a perfect radiator. 2. $J=A\lambda^{-\alpha}e^{-\frac{B}{\lambda}}$. T=absolute temperature.
e=Naperian Base.

218. Emission with single maximum and variable temperature. 3. $J=c_1\lambda^{-\alpha}e^{-\frac{c_2}{\lambda T}}$. . . . Wien's Formula.

219. Constants. $a=A\lambda^{-\alpha}=c_1\lambda^{-\alpha}$, $b=\frac{B}{\lambda}=\frac{c_2}{\lambda}$, $\alpha=5$.

$$\left.\begin{aligned}c_1&=\frac{J_m}{T^5}(\lambda_m Te)^5=\frac{J_m}{T^5}\left(\frac{c_2e}{5}\right)^5\\ c_2&=5\lambda_mT=5\times2891=14455\end{aligned}\right\}\text{Paschen.}$$

		Formula.	Energy Curves.	Isochromatic Curves.	
220. For low temperatures and long wave lengths. $T=273°$ to $750° C$.	c_1	633000	634600	631900	Watts/cm^2.
	c_1'	152290	152330	151680	$\frac{\text{Gr. Cal.}}{\text{sec}}/cm^2$.
	c_2	14455	14455	14455	
221. For high temperatures and short wave lengths. $T=750°$ to $1500° C$.	c_1'	**146030**	145870	145300	
	c_2	**14531**	14514	14520	

c_1' for low temperatures $=\frac{c_1}{4.166}$, where $\frac{\text{Gr. Cal.}}{\text{sec}}\cdot\frac{1}{cm^2}\times4.166=\text{Watts}\cdot\frac{1}{cm^2}$.

222. Maximum emission. 4. $J_m=c_1\left(\frac{\alpha}{c_2e}\right)^{\alpha}T^{\alpha}=c_1\left(\frac{5}{c_2e}\right)^5T^5 \qquad =BT^5$.

223. Maximum wave length.	5.	$\lambda_m=\frac{c_2}{\alpha T} \quad =\frac{c_2}{5T} \quad =\frac{A}{T}.$
224. Total intensity of emission, which is the heat equivalent of total radiation emitted by a black body at temperature T.	6.	$J_o=\int_o^\infty J d\lambda \quad =c_1 c_2^{1-a}\Gamma(\alpha-1)T^{a-1}=\sigma T^4.$ $=6\frac{c_1}{c_2^4}T^4.$ . . . Stefan's Law. $=1.277\times10^{-12}T^4\frac{\text{Gr. Cal.}}{cm^2\text{sec}}$ $=5.32\times10^{-12}\ .\ T^4\frac{\text{Watts}}{cm^2}.$
225. Constants.	7.	$C_1=9292\frac{\text{Gr. Cal.}}{cm^2\text{sec}}\times\mu^4=38710\frac{\text{Watts}}{cm^2}\times\mu^4.$
Heat equivalent of the total radiation by ideal black body at T.		$C_2=14455\mu\ .\ T$ degrees.
(A probably varies with T.)		$A=\lambda_m T=2891. \qquad \lambda T=$constants.
		$B=\frac{J_m}{T^5}=2.120\times10^{-14}.$
226. Ratio of intensities.	8.	$\frac{J}{J_m}=\left\{\frac{\lambda_m}{\lambda}e^{\frac{\lambda-\lambda_m}{\lambda}}\right\}^a.$
227. Add a sharp maximum of constant wave length.	9.	$J=c_1(\lambda-\lambda_m)^{-a}e^{-\frac{c_2}{\lambda T}}.$
228. Restrict to real values.	10.	$J=c_1\lambda^{-a}e^{-\frac{c_2}{\lambda T}}(\lambda-\lambda_m)^{-2}.$
229. Add several maxima or spectral lines.	11.	$J=c_1\lambda^{-a}e^{-\frac{c_2}{\lambda T}}\Sigma_{m=1}^{m}(\lambda-\lambda_m)^{-2},$

where $(\lambda-\lambda_m)^{-2}$ is the sharp maximum of each line, and λ . . . . λ_m include the reflection, refraction, and absorption wave lengths.

λ_m is probably dependent upon the molecular or atomic period.

Near λ_m and within a few octaves of it, emission by (11) is much less than by (3), using the same constants.

On the side of the *short* periods from λ_m (3) does not hold perfectly.

On the side of the *long* periods from λ_m the emission is like that from a black body and is given by (3).

TABLE 42.—*Heliographic positions.*

[Referred to the north side of the ecliptic.]

230. Poles. S=sun; E=earth; K=ecliptic; C=coronal axis.

231. Inclinations.
I=sun's equator to ecliptic= 7° 15′.
ω=earth's equator to ecliptic=23° 27′.
$(H+G)$=earth's equator to sun's equator=26° 20′ (in maximum)

232. Distances.
R=solar radius on photograph; R' corrected for distortion.
r=spot from center of picture; r' " " "
R''=sun's radius in the ephemeris.
ρ'=measured distance of spot from center in terms of R''.

233. Angles.

ρ=heliocentric angle of sun spot Σ from earth.

$G=EO'K$ (+ when E is east of K).

$H=KO'S$ (+ when K is east of S).

$P=SO'E$ (+ from E through east).

$\chi=P+G+H$.

O = projection of O′ on the plane through Σ.

Σ'= projection of Σ on the plane through O′.

O′= center of sun.

234. Longitudes.

$\odot$=sun's celestial.

N=sun's ascending node=73° 40′ (1850).

L=nodal heliocentric of earth $C=NO'C$.

l=nodal heliocentric of spot $\Sigma=NO'\Sigma$.

$L-l$=heliocentric of spot Σ from the central meridian= $CO'\Sigma$.

l'=heliocentric of prime meridian M from $N=NO'M$.

$L-l'$=heliocentric of center of disk O from $M=MO'O$.

$l-l'$=heliocentric of the sun spot Σ from $M=\Sigma O'M$.

235. Latitudes.

D=sun's equator to the ecliptic.

F=sun's equator to the earth's equator.

d=sun's equator to the spot Σ.

236. Time.

T=the fraction of a revolution executed by the prime meridian at a given date.

t=time from epoch. Epoch=1854−0^d.0=mean midnight Dec. 31, 1853.

κ =mean angular velocity of sun on its axis.

n=mean angular velocity of earth around sun.

$\kappa-n$=synodic angular velocity of the sun.

m=complete number of siderial rotations of the M since the epoch.

237. 1. $\tan G=\tan\omega\cos\odot$. $+$=east; $-$=west.

238. 2. $\tan H=\tan I\cos(\odot-N)$. $+$=east; $-$=west.

239. 3. $\tan L=\cos I\tan(\odot-N)$.

240. 4. $\sin D=\sin I\sin(\odot-N)$. $+$=north; $-$=south.

241. 5. $\rho'=\frac{r'}{R'}(R'')$.

242. 6. $\rho=\sin^{-1}\frac{r'}{R'}-\rho'$.

243. 7. $\sin d=\cos\rho\sin D+\sin\rho\cos D\cos\chi$.

244. 8. $\tan F=\tan\omega\sin\odot$. $+$=north; $-$=south.

245. 9. $\sin(L-l)=\sin\chi\sin\rho\sec d$.

246. 10. $T=\frac{t}{24.863}-m$.

247. 11. $l'=T\times\frac{360}{24.863}=T\times 14.4783$. (Bigelow.)

$=T\times 14.1844$. (Carrington.)

References: Carrington. Observations at Redhill, London, 1863.
Very. Astrophysics, Oct.-Dec., 1897; Jan., 1898.
Bigelow. Weather Bureau Bulletin No. 21.
Astrophysics, Nov., 1893.

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